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(54) **RADIO FREQUENCY SYSTEMS AND METHODS FOR CONTROLLING SPURIOUS EMISSIONS**

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H04B 17/14 (2015.01)
H04B 1/04 (2006.01)
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CPC *H04B 17/14* (2015.01); *H04B 1/0475* (2013.01); *H04B 17/0085* (2013.01); *H04B 2001/0408* (2013.01)

(58) **Field of Classification Search**
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USPC 375/227, 224
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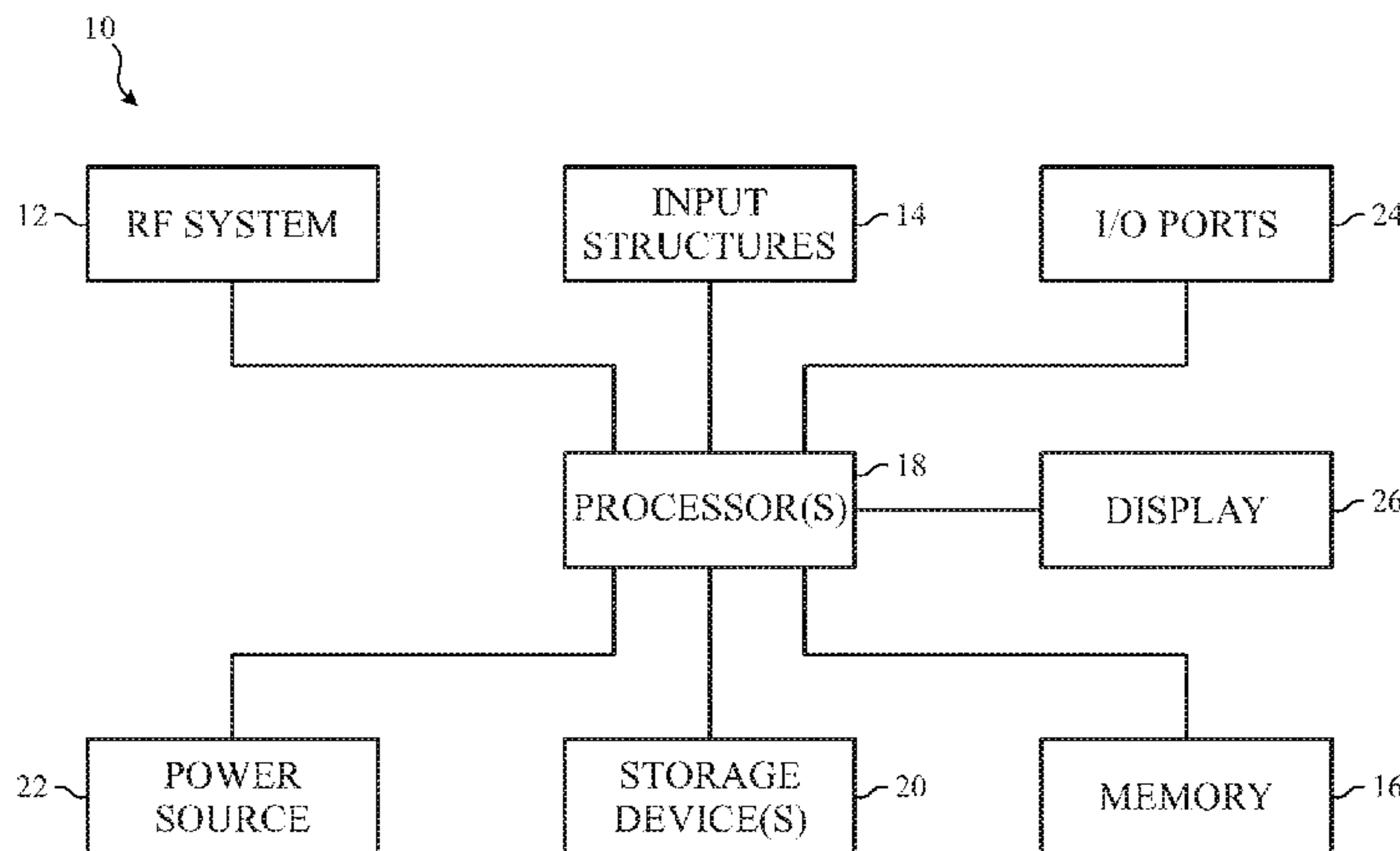
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(57) **ABSTRACT**

Systems and method for improving performance of a radio frequency system are provided. One embodiment describes a radio frequency system, which includes an antenna that wirelessly transmits analog electrical signals at a desired transmission frequency; a feedback receiver that determines a feedback signal, which includes a portion of a transmitted analog electrical signal via a coupler; and a controller that determines location and magnitude of spurious emissions transmitted at frequencies other than the desired transmission frequency by comparing the feedback signal with a desired signal, in which the desired signal includes a digital electrical signal that does not contain noise introduced by the radio frequency system; and instructs the radio frequency system to adjust operational parameters used to transmit the analog electrical signals when the magnitude of the spurious emissions exceeds a spurious emissions limit at the determined location.

17 Claims, 8 Drawing Sheets



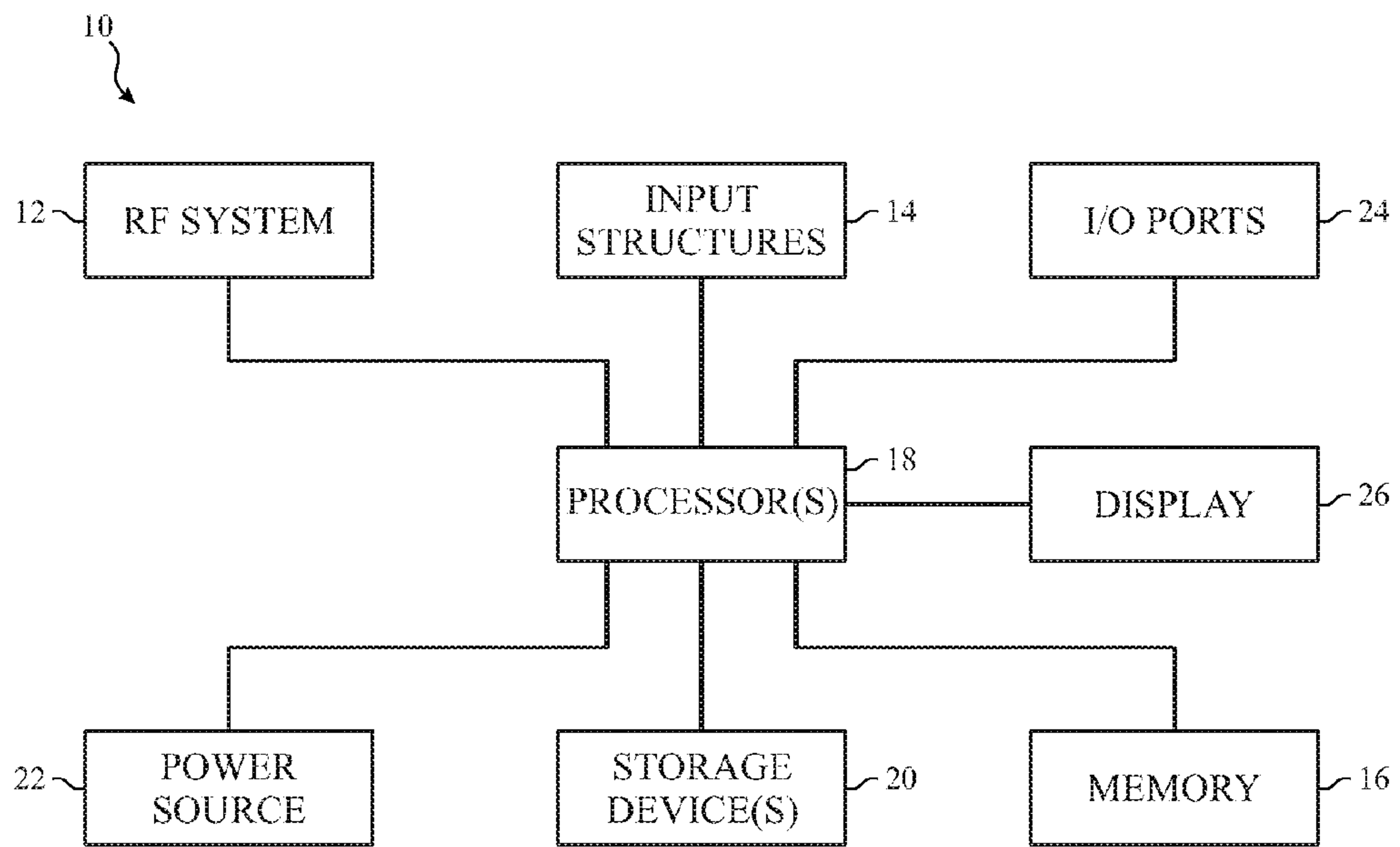


FIG. 1

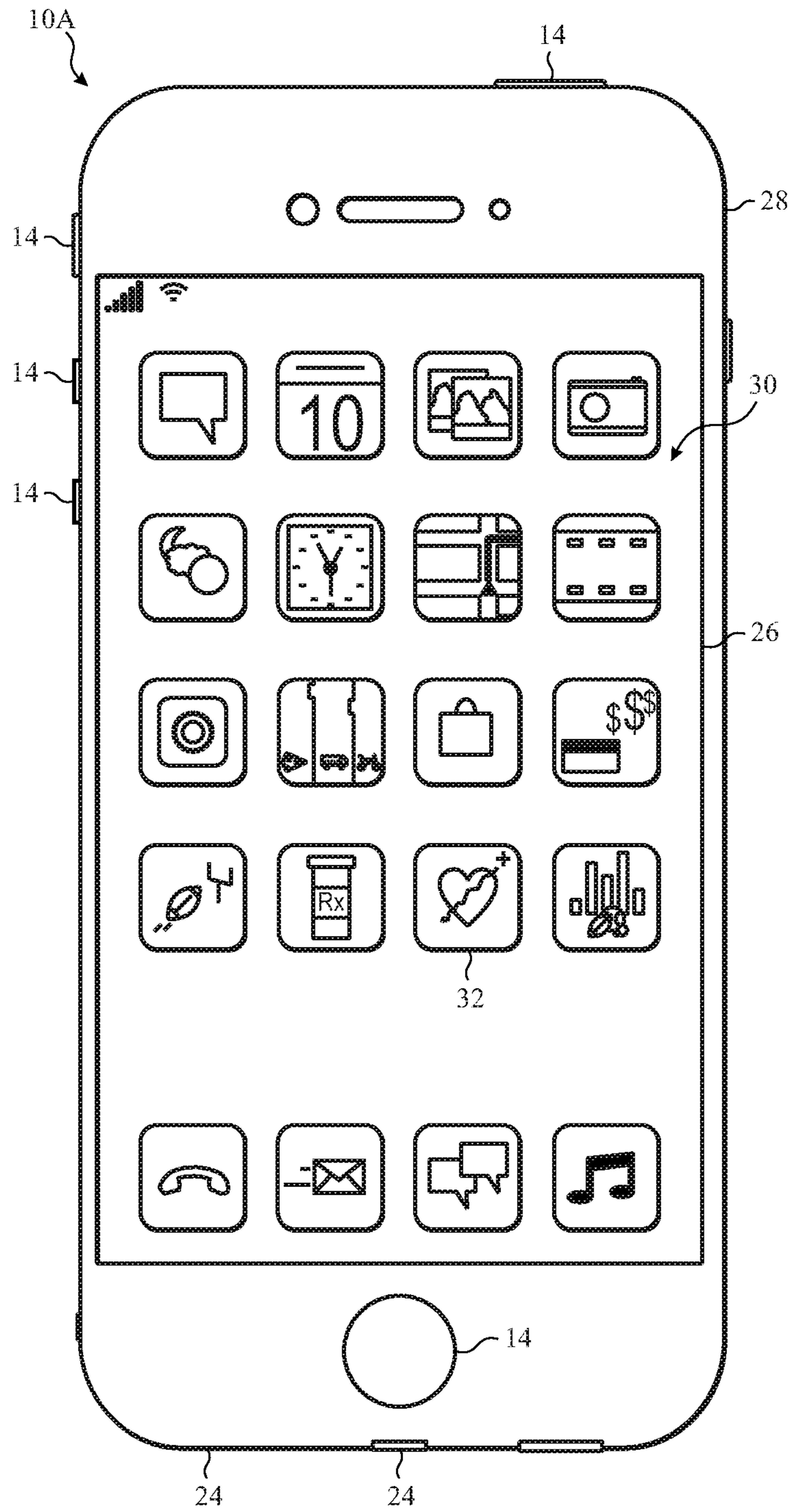


FIG. 2

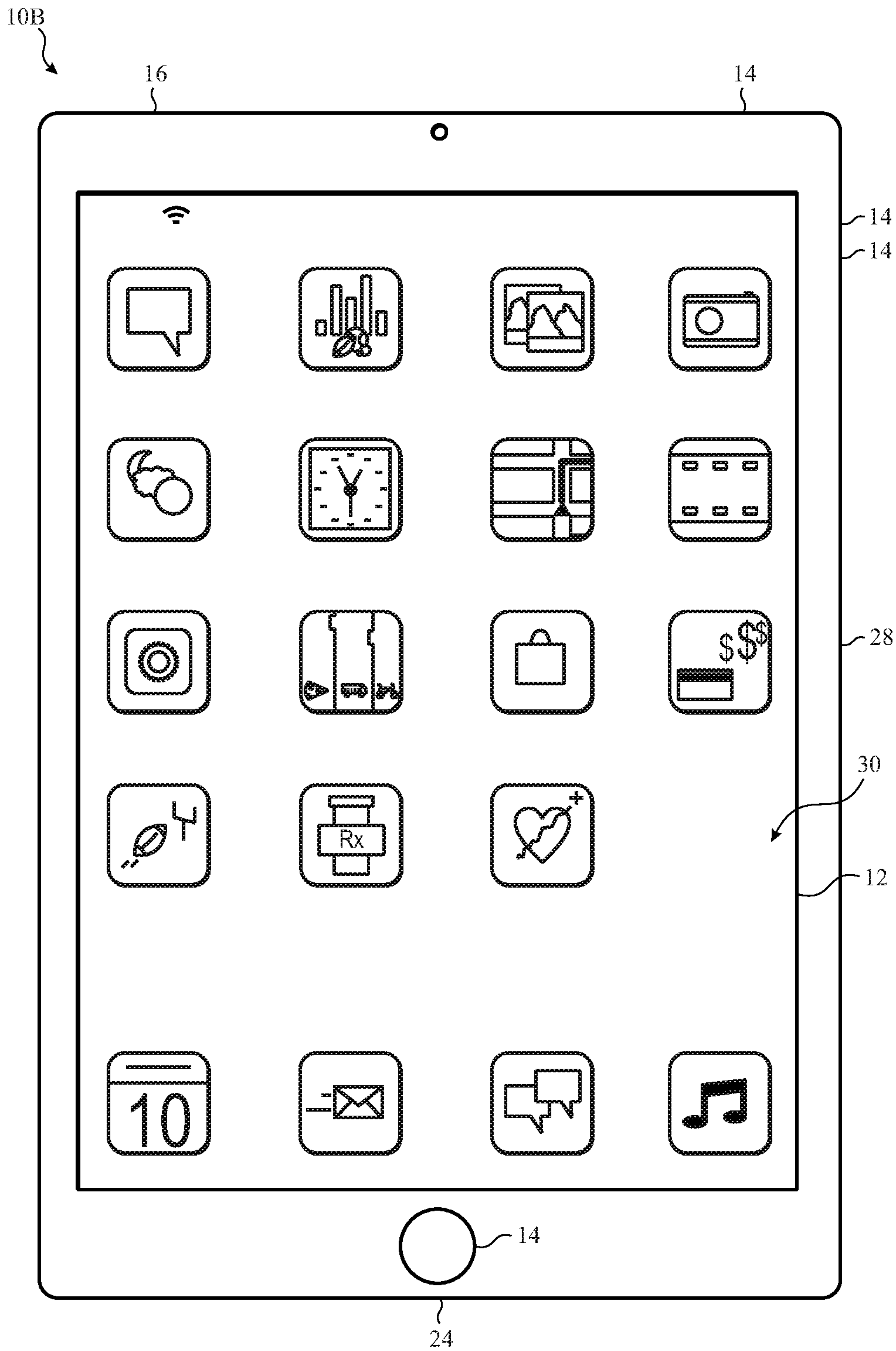


FIG. 3

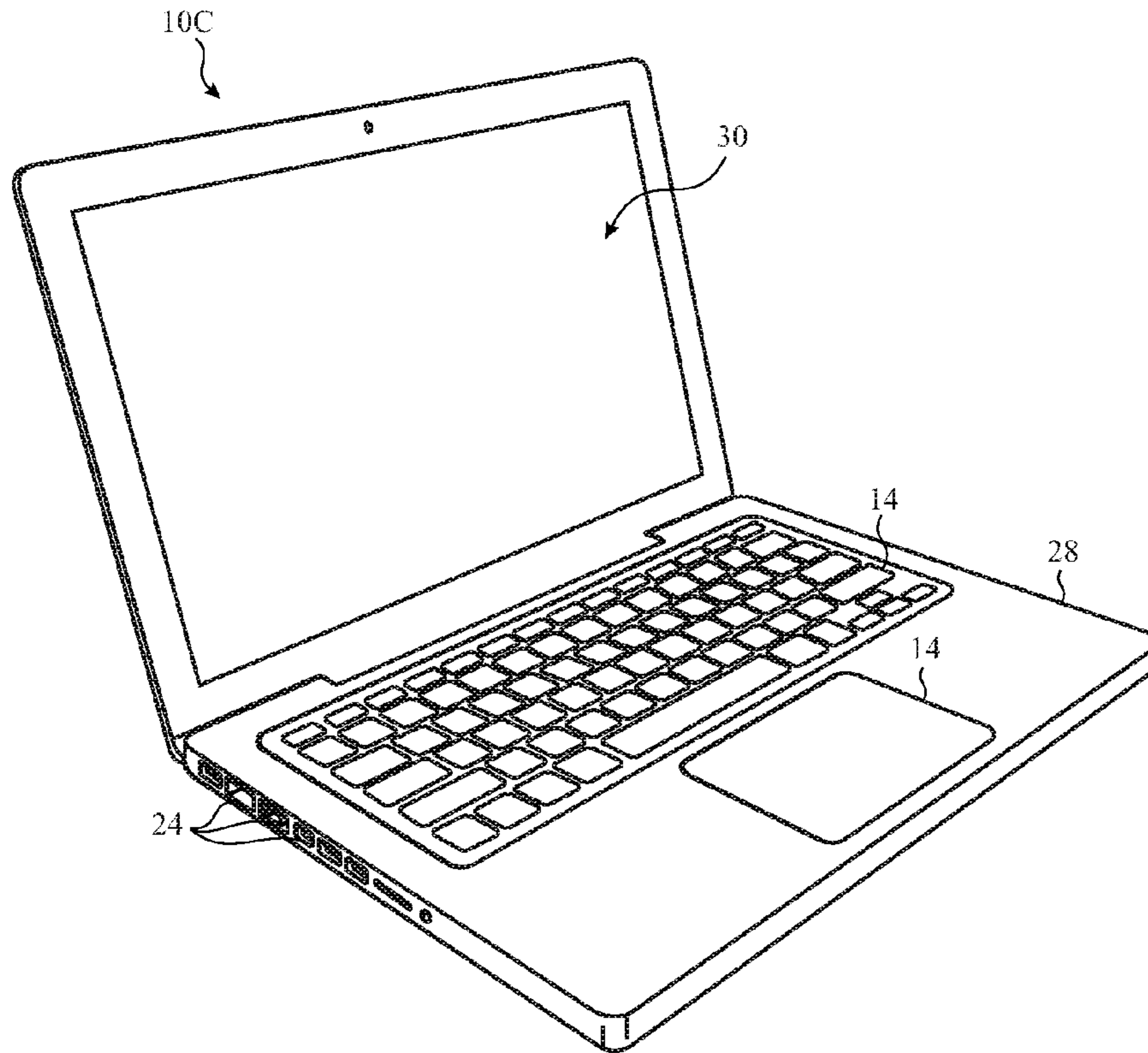


FIG. 4

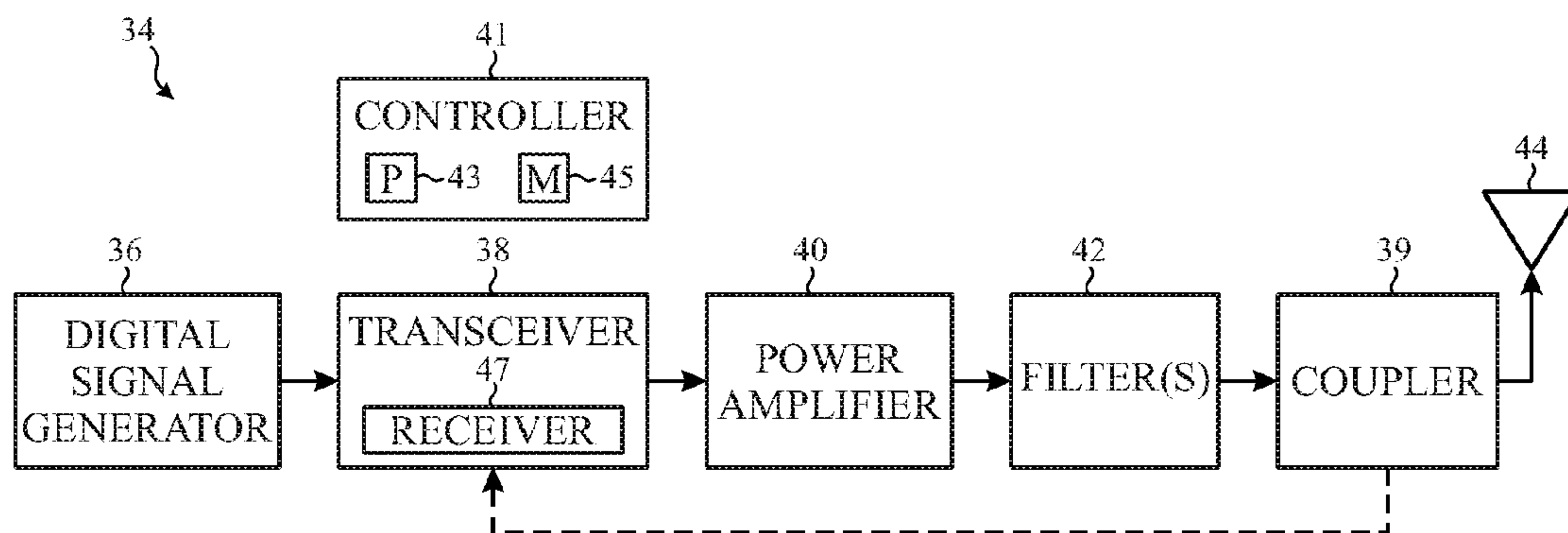


FIG. 5

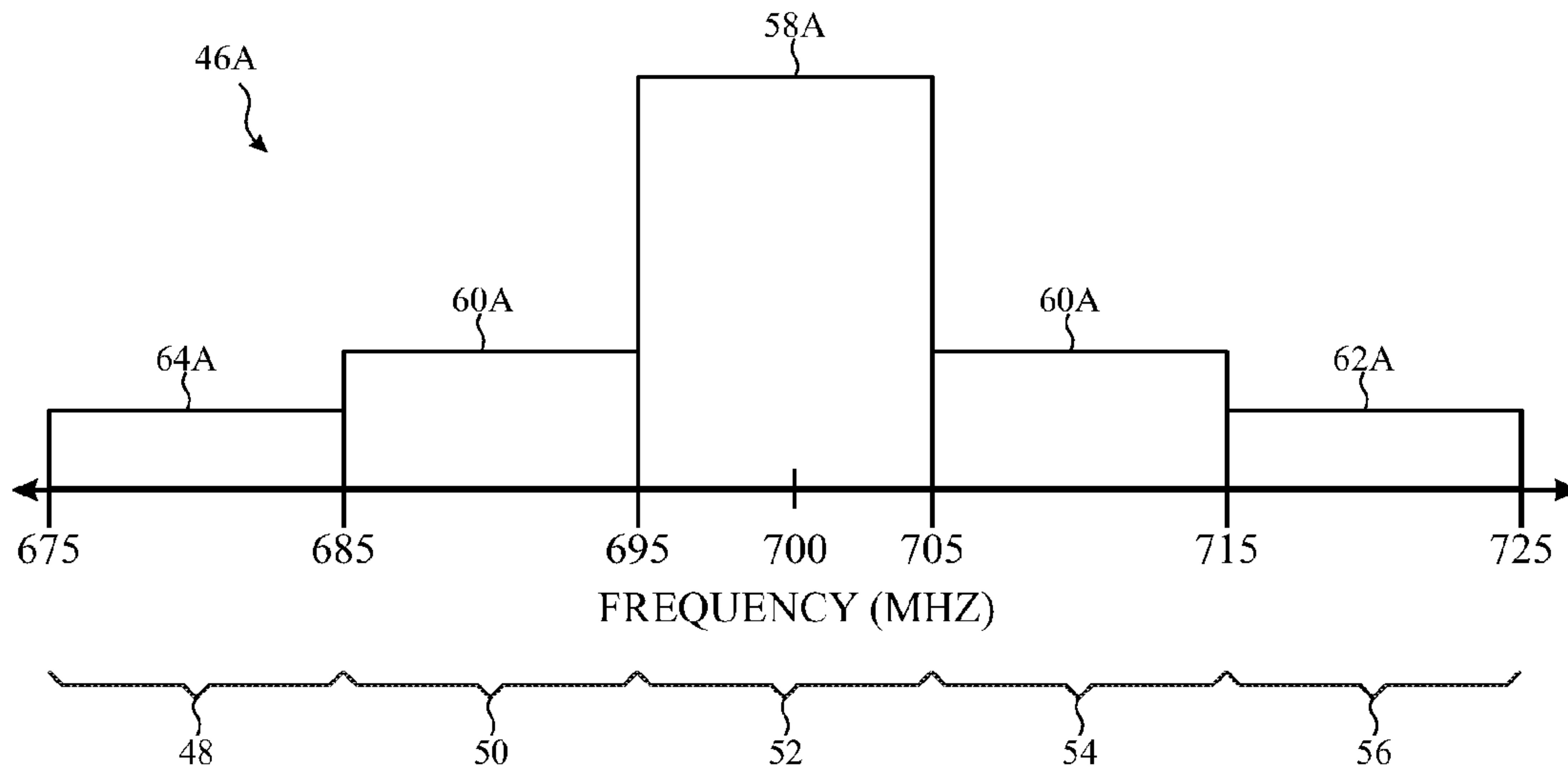


FIG. 6A

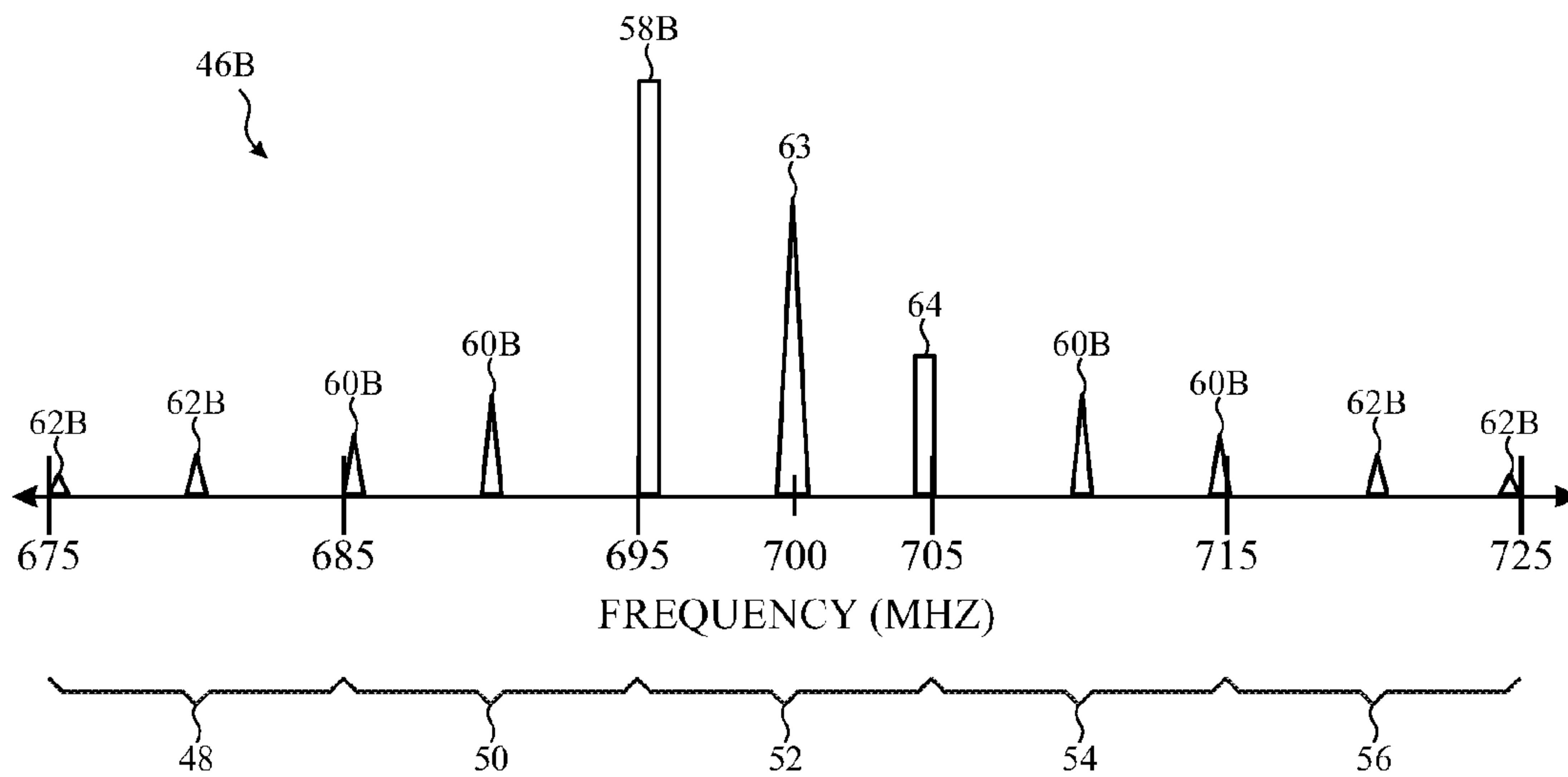


FIG. 6B

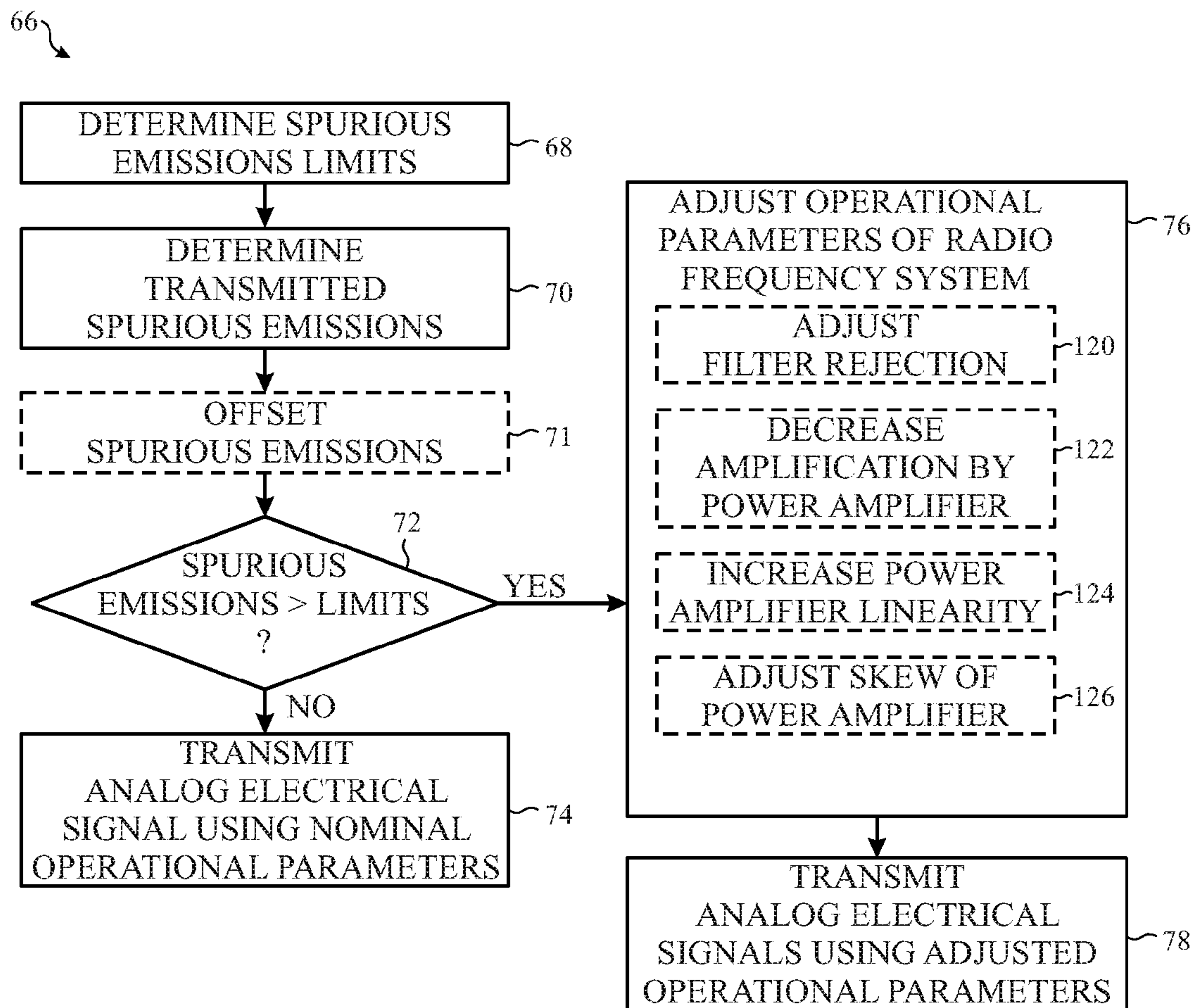


FIG. 7

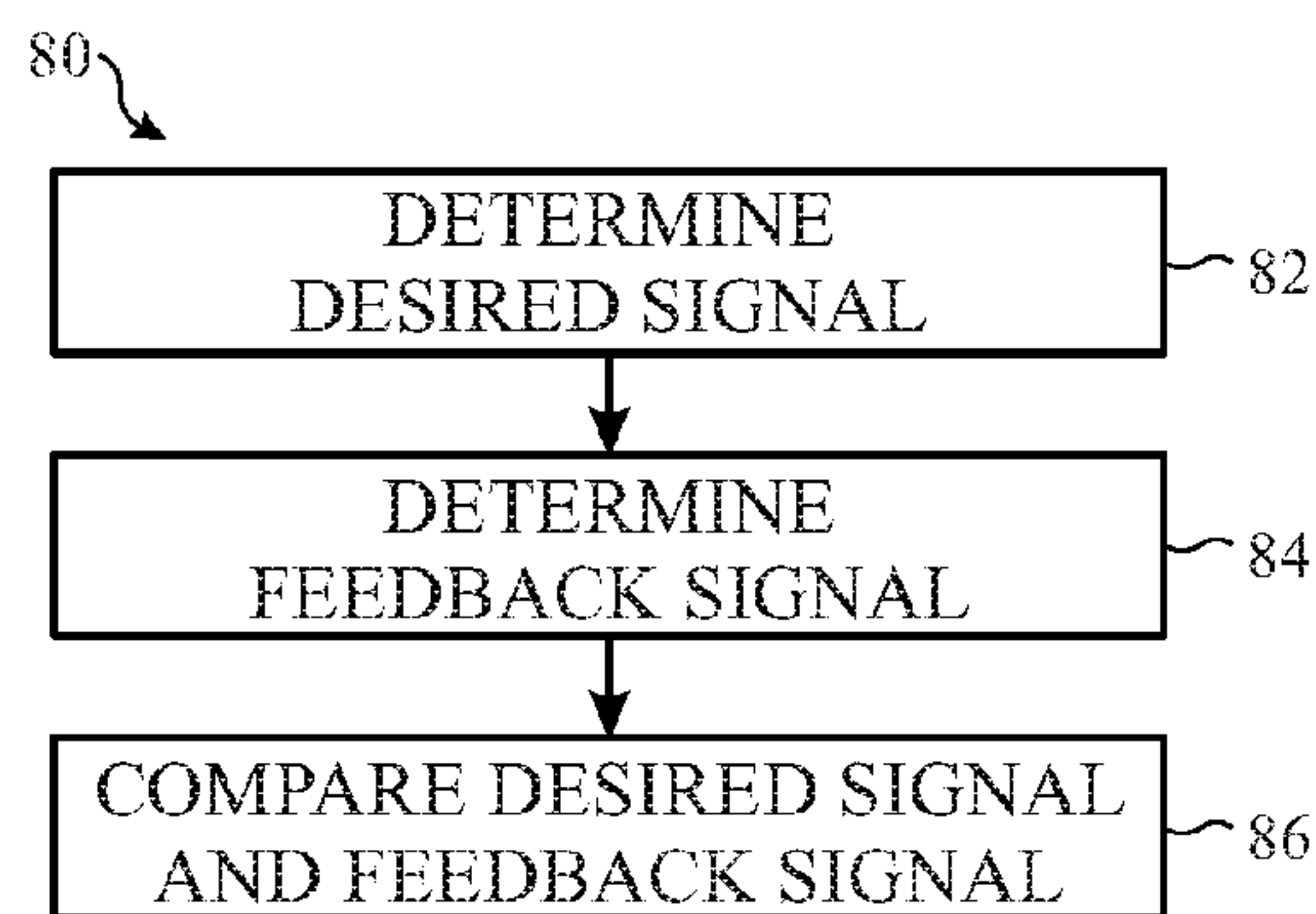


FIG. 8

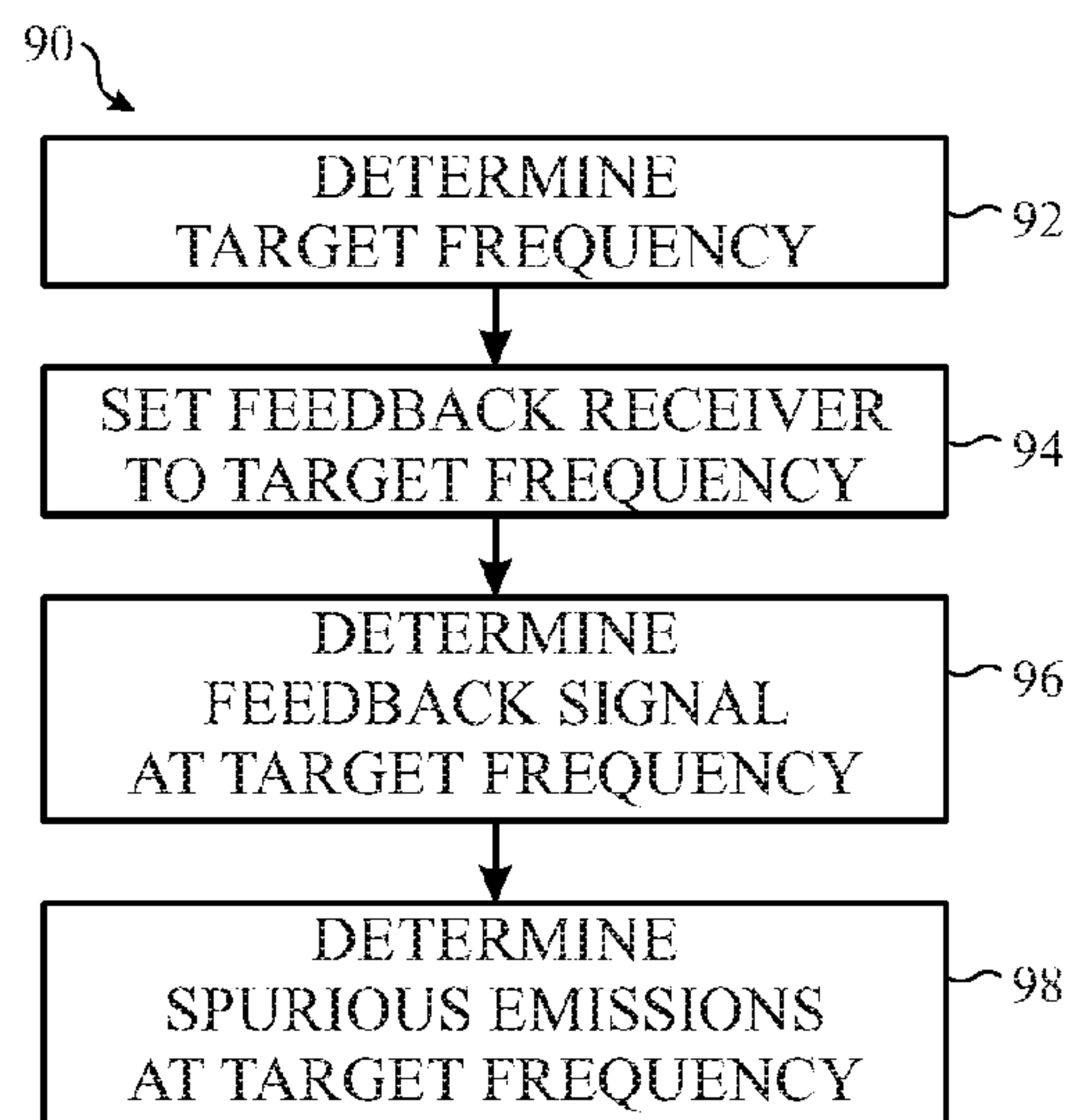


FIG. 9

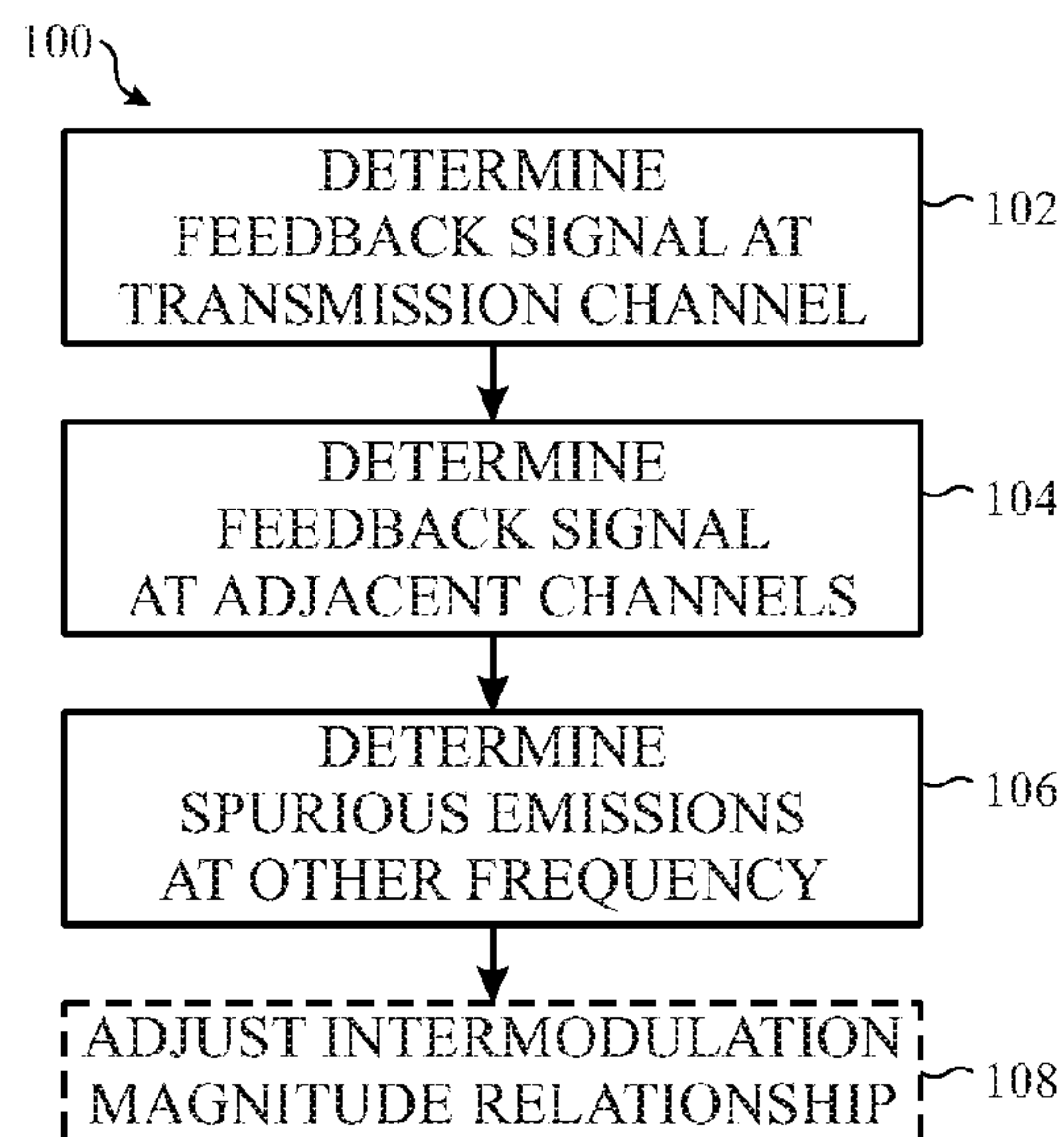
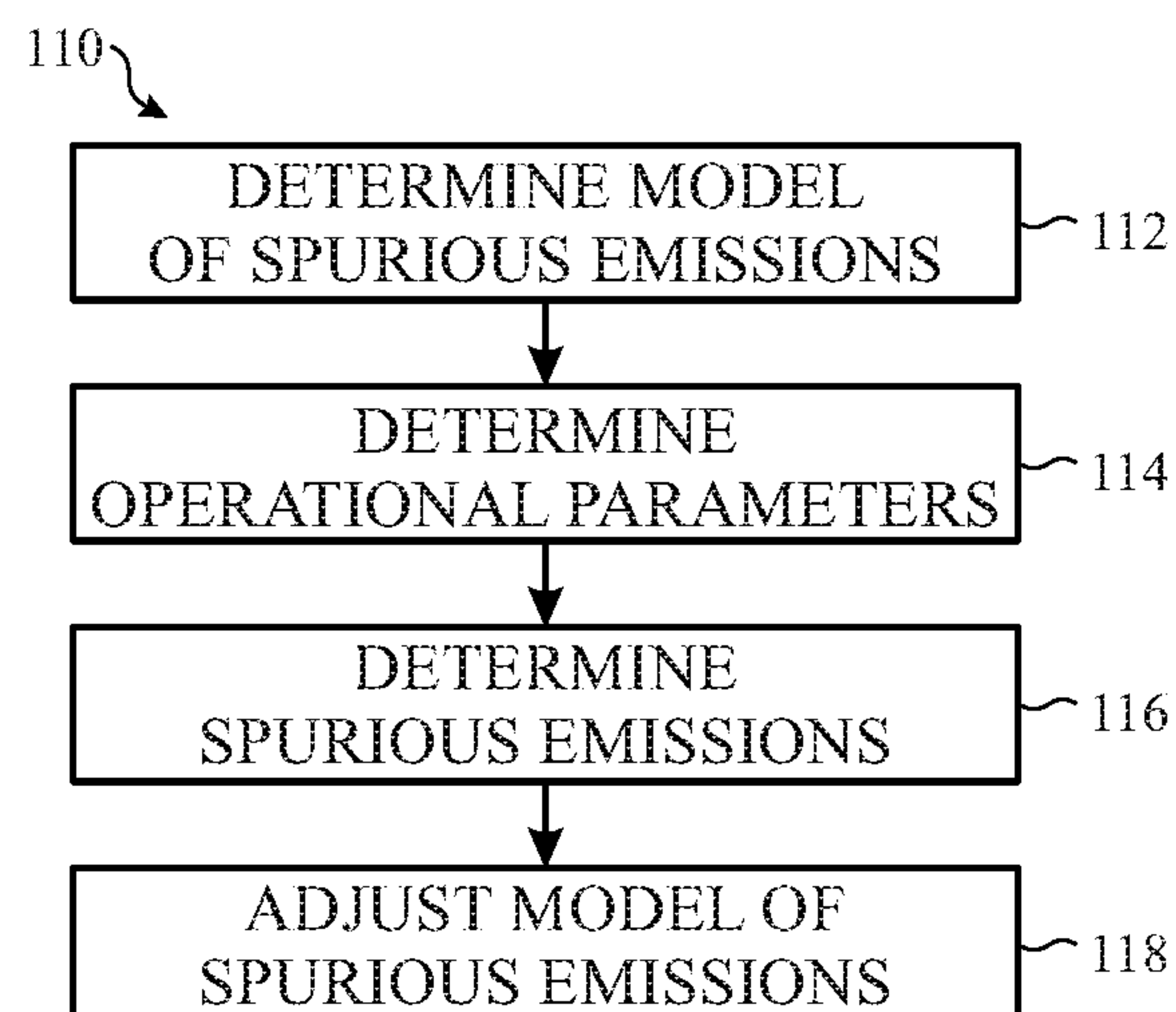
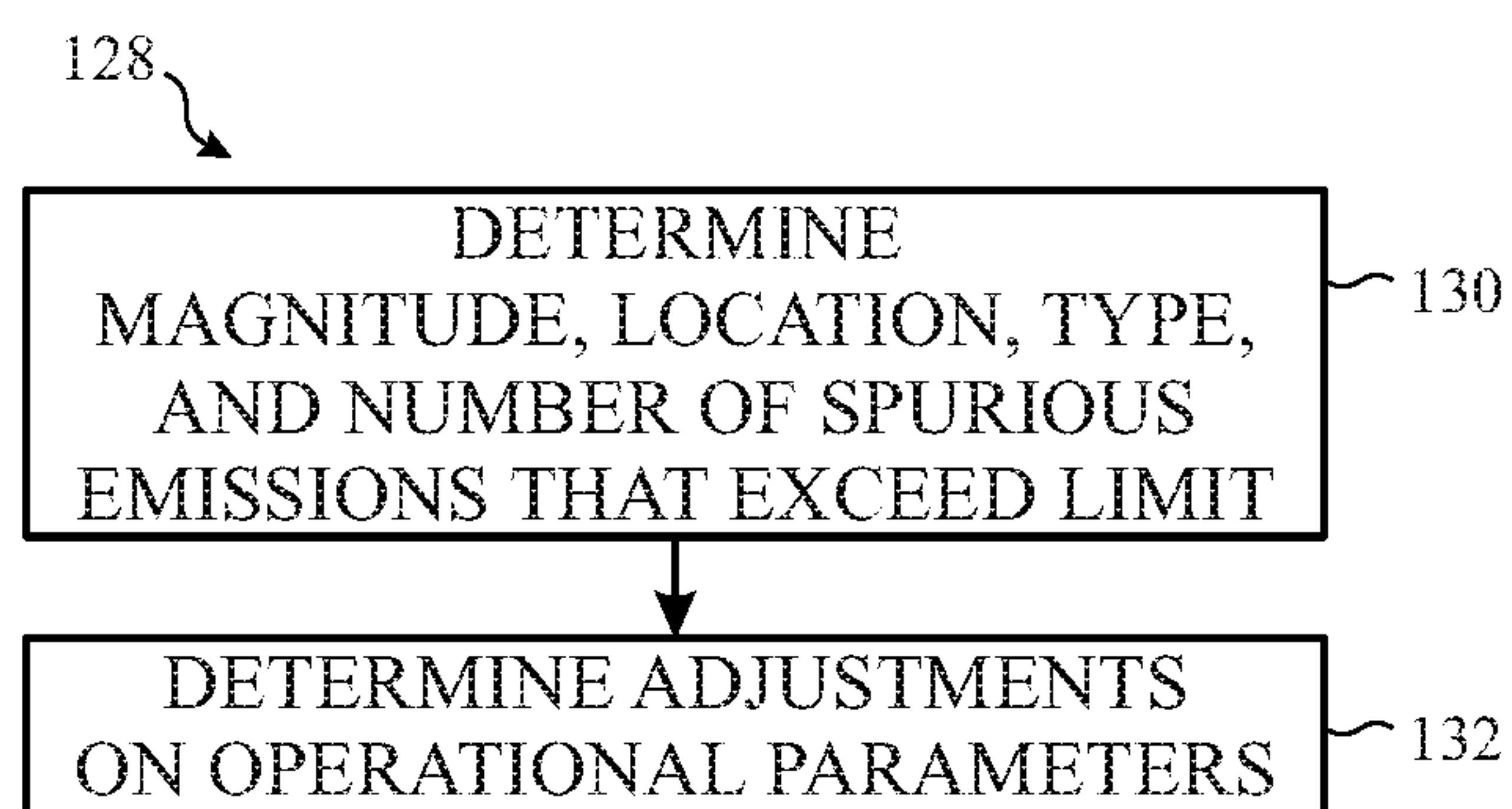


FIG. 10

*FIG. 11**FIG. 12*

RADIO FREQUENCY SYSTEMS AND METHODS FOR CONTROLLING SPURIOUS EMISSIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

Under 35 U.S.C. §120, this application is a continuation of U.S. patent application Ser. No. 14/635,660 filed on Mar. 2, 2015, which is incorporated by reference herein in its entirety for all purposes.

BACKGROUND

The present disclosure relates generally to radio frequency systems and, more particularly, to controlling spurious emissions produced by a radio frequency system.

This section is intended to introduce the reader to various aspects of art that may be related to various aspects of the present techniques, which are described and/or claimed below. This discussion is believed to be helpful in providing the reader with background information to facilitate a better understanding of the various aspects of the present disclosure. Accordingly, it should be understood that these statements are to be read in this light, and not as admissions of prior art.

Many electronic devices may include a radio frequency system to facilitate wireless communication of data with other electronic devices and/or a network. The radio frequency system may include a transceiver that receives a digital representation of data as a digital electrical signal and generates an analog representation of the data as an analog electrical signal. A power amplifier may then amplify the analog electrical signal to a desired output power for wireless transmittance via an antenna at a desired radio frequency, such as an assigned resource block or channel. As used herein, a “channel” is intended to describe a range of frequencies and a “resource block” is intended to describe a range of frequencies within the channel.

Generally, regulations on wireless transmissions are set by regulatory bodies, such as the Federal Communications Commission (FCC) in the United States, Industry Canada (IC) in Canada, the Ministry of Internal Affairs and Communications (MIC) in Japan, and the European Telecommunications Standards Institute (ETSI) in Europe. More specifically, such regulatory bodies may set allowable spurious emissions limits for radio frequency systems, particularly in protected or restricted frequency bands. As used herein, a “frequency band” is intended to describe a range of radio frequencies including multiple channels and “spurious emissions” are intended to describe wireless signal transmission at frequencies other than a desired transmission frequency.

In some embodiments, spurious emissions may be the result of noise introduced into the analog electrical signal, for example, by the transceiver and/or the power amplifier. As a result, when the antenna transmits the analog electrical signal at a desired transmission frequency, spurious emissions may also be transmitted at other frequencies. More specifically, the magnitude and location (e.g., frequency) of the spurious emissions may be affected by operational parameters, such as ambient temperature, transmission frequency, output power, antenna load, and the like. In other words, even though the operational parameters may change, the radio frequency system should still operate to meet any spurious emissions limits.

SUMMARY

A summary of certain embodiments disclosed herein is set forth below. It should be understood that these aspects are

presented merely to provide the reader with a brief summary of these certain embodiments and that these aspects are not intended to limit the scope of this disclosure. Indeed, this disclosure may encompass a variety of aspects that may not be set forth below.

The present disclosure generally relates to improving performance of a radio frequency system by controlling operation of the radio frequency system based at least in part on output spurious emissions. Generally, the radio frequency system may wirelessly communicate data with other electronic devices and/or a network by modulating radio waves at a desired transmission frequency based on an analog representation of the data (e.g., an analog electrical signal). However, the analog electrical signal may contain noise introduced by the components in the radio frequency system, which may cause the radio frequency system to transmit spurious emissions at other frequencies.

Although some amount of spurious emissions may be acceptable, the radio frequency system should still operate within set spurious emissions limits, particularly at protected or restricted frequency bands. However, the amount of spurious emissions transmitted by the radio frequency system may be dependent on the operational parameters, such as ambient temperature, transmission frequency, output power, antenna load, and the like. In other words, the amount of spurious emissions may be dynamic over operation of the radio frequency system.

Accordingly, the techniques described herein may improve operation of the radio frequency system by enabling dynamic control based at least in part on spurious emissions. In some embodiments, the radio frequency system may include a coupler that feeds back the analog electrical signal transmitted by an antenna to a feedback receiver. The feedback receiver may then compare the feedback signal with an ideal desired signal (e.g., a digital electrical signal). Based at least in part on the comparison, the radio frequency system may determine distortion (e.g., spurious emission) in the transmitted analog electrical signal introduced by the radio frequency system (e.g., a power amplifier and/or a transceiver). In some embodiments, the feedback receiver may be tuned to determine the spurious emissions at a particular out of band frequency (e.g., frequency outside of desired transmission frequency). In other embodiments, the feedback receiver may determine the spurious emissions at a range of frequencies around the transmission frequency, which may then be used to determine spurious emissions at other frequencies.

In this manner, the radio frequency system may determine the location (e.g., frequency) and/or magnitude of spurious emissions transmitted and adjust operational parameters of the radio frequency system when necessary. More specifically, the radio frequency system may operate using nominal operational parameters when the nominal operational parameters do not result in exceeding spurious emissions limits. However, when spurious emissions limits are exceeded, the radio frequency system may adjust operational parameters of the radio frequency system away from the nominal operational parameters. For example, in some embodiments, the radio frequency system may increase filter rejection, decrease amplification by a power amplifier, increase power amplifier linearity, adjust the skew of the power amplifier emissions (e.g., favor emissions on one side of the transmission frequency, which may land in a protected band, at the expense of emissions on the other side, which may have no emissions constraints), or any combination thereof.

However, adjustments of operational parameters away from the nominal operational parameters may affect performance of the radio frequency system, particularly power consumption, efficiency, and/or output power. As such, the techniques provided herein enable performance of the radio frequency system to be improved by predominantly using nominal operational parameters and dynamically adjusting the operational parameters of the radio frequency system based on spurious emissions.

BRIEF DESCRIPTION OF THE DRAWINGS

Various aspects of this disclosure may be better understood upon reading the following detailed description and upon reference to the drawings in which:

FIG. 1 is a block diagram of a electronic device with a radio frequency system, in accordance with an embodiment;

FIG. 2 is an example of the electronic device of FIG. 1, in accordance with an embodiment;

FIG. 3 is an example of the electronic device of FIG. 1, in accordance with an embodiment;

FIG. 4 is an example of the electronic device of FIG. 1, in accordance with an embodiment;

FIG. 5 is block diagram of a portion of the radio frequency system of FIG. 1, in accordance with an embodiment;

FIG. 6A is a plot of a first analog electrical signal transmitted by the radio frequency system of FIG. 5, in accordance with an embodiment;

FIG. 6B is a plot of a first analog electrical signal transmitted by the radio frequency system of FIG. 5, in accordance with an embodiment;

FIG. 7 is a flow diagram describing a process for transmitting analog electrical signals using the radio frequency system of FIG. 5, in accordance with an embodiment;

FIG. 8 is a flow diagram describing a process for determining spurious emissions based on a feedback signal, in accordance with an embodiment;

FIG. 9 is a flow diagram describing a process for determining spurious emissions using a dedicated coupler, in accordance with an embodiment;

FIG. 10 is a flow diagram describing a process for determining spurious emissions using a shared coupler, in accordance with an embodiment;

FIG. 11 is a flow diagram describing a process for determining spurious emissions based on a model, in accordance with an embodiment; and

FIG. 12 is a flow diagram describing a process for determining adjustments to operational parameters of the radio frequency system of FIG. 5, in accordance with an embodiment.

DETAILED DESCRIPTION

One or more specific embodiments of the present disclosure will be described below. These described embodiments are only examples of the presently disclosed techniques. Additionally, in an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but may neverthe-

less be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

When introducing elements of various embodiments of the present disclosure, the articles "a," "an," and "the" are intended to mean that there are one or more of the elements. The terms "comprising," "including," and "having" are intended to be inclusive and mean that there may be additional elements other than the listed elements. Additionally, it should be understood that references to "one embodiment" or "an embodiment" of the present disclosure are not intended to be interpreted as excluding the existence of additional embodiments that also incorporate the recited features.

As mentioned above, an electronic device may include a radio frequency system to facilitate wirelessly communicating data with another electronic device and/or a network. More specifically, the radio frequency system may modulate radio waves at a desired radio frequency, such as an assigned one or more resource block or channel, to enable the electronic device to communicate via a personal area network (e.g., Bluetooth network), a local area network (e.g., an 802.11x Wi-Fi network), and/or a wide area network (e.g., a 4G or LTE cellular network). In other words, the radio frequency systems may utilize various wireless communication protocols to facilitate communication of data.

Nevertheless, radio frequency systems may generally be operationally similar regardless of the wireless communication protocol used. For example, to transmit data, processing circuitry may generate a digital representation of the data as a digital electrical signal and a transceiver (e.g., a transmitter and/or a receiver) may then convert the digital electrical signal into one or more analog electrical signals. The analog electrical signal may then be amplified by a power amplifier, filtered by one or more filters, and transmitted by an antenna.

However, along with the data, the radio frequency system may also transmit spurious emissions. In some embodiments, the spurious emissions may be the result of noise introduced into the analog electrical signal by the transceiver and/or the power amplifier. For example, the transceiver may introduce noise as a result of digital signal modulation or analog impairments in the modulator, mixer, or driver amplifier and the power amplifier may introduce noise as a result of non-linearities. In some embodiments, adjacent channel leakage ratio (ACLR) may be used as a metric for spurious emissions levels outside the desired transmission frequency (e.g., allocated transmission channel).

In some instances, the spurious emissions may be transmitted at frequencies other than a desired transmission frequency. More specifically, spurious emissions may leak into frequencies surrounding the transmission frequency. For example, a radio frequency system transmitting a 10 MHz wide channel centered at 700 MHz (e.g., 695-705 MHz allocated bandwidth), may generate adjacent channel spurious emissions due to 3rd order products between 685-715 MHz, 5th order products between 675-725 MHz, and so on with higher order products. Additionally, spurious emissions may occur at harmonics of the transmission frequency. For example, continuing with the above example, spurious emissions may occur at 1400 MHz (e.g., second harmonic), 2100 MHz (e.g., third harmonic), and so on.

However, regulatory bodies generally place a limit on amount of acceptable spurious emissions. In fact, some regulatory bodies may restrict wireless transmission at certain frequencies and only allow spurious emissions below a specified limit. For example, the FCC mandates that only spurious emissions are permitted at frequencies between

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608-614 MHz. Moreover, the FCC mandates that the magnitude of the spurious emissions be less than 200 microvolts/meter.

As such, a radio frequency system should operate such that spurious emissions are lower than the set limits. Generally, spurious emissions vary based on operational parameters, such as ambient temperature, transmission frequency, output power, antenna load, and the like. For example, spurious emissions may increase as temperature increases. Additionally, spurious emissions are more likely to fall within protected frequencies when the transmission frequency is closer to the protected frequencies. Furthermore, magnitude of spurious emissions may increase as magnitude (e.g., output power) of the transmitted analog electrical signals is increased. In other words, the position (e.g., frequency) and magnitude of spurious emissions may dynamically vary over the course of operation of the radio frequency system.

Accordingly, as will be described in more detail below, performance of the radio frequency system may be improved by dynamically controlling operational parameters of the radio frequency system based at least in part on spurious emissions. In some embodiments, the radio frequency system may determine spurious emissions based at least in part on feedback of the analog electrical signal transmitted by the antenna. More specifically, the radio frequency system may determine location and/or magnitude of any spurious emissions by comparing the feedback signal (e.g., portion of the transmitted analog electrical signal) with a desired signal (e.g., ideal digital electrical signal), which does not include noise introduced by the radio frequency system.

Based on the determined spurious emissions, the radio frequency system may adjust operational parameters of the radio frequency system, particularly when the spurious emissions exceeded set limits. More specifically, when below spurious emissions limits, the radio frequency system may operate using nominal operational parameters. On the other hand, when limits are exceeded, the radio frequency system may adjust operational parameters of the radio frequency system. For example, the radio frequency system may increase filter rejection, decrease amplification by a power amplifier, increase power amplifier linearity, adjust the skew of the power amplifier emissions (e.g., favor emissions on one side of the transmission frequency, which may land in a protected band, at the expense of emissions on the other side, which may have no emissions constraints), or any combination thereof.

However, adjustments away from the nominal operational parameters may affect performance of the radio frequency system. For example, increasing filter rejection and/or output power may reduce reliability of transmissions by the radio frequency system. Additionally, increasing the filter rejection and/or increasing linearity of the power amplifier may increase power consumption, thereby decreasing efficiency (e.g., output power/DC power consumption). Furthermore, adjusting skew of the power amplifier may introduce spurious emissions at other frequencies.

In other words, the techniques may improve performance of a radio frequency system by predominantly using the nominal operational parameters and dynamically adjusting the operational parameters of the radio frequency system based on spurious emissions. To help illustrate, an electronic device **10** that may utilize a radio frequency system **12** is described in FIG. 1. As will be described in more detail below, the electronic device **10** may be any suitable elec-

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tronic device, such as a handheld computing device, a tablet computing device, a notebook computer, and the like.

Accordingly, as depicted, the electronic device **10** includes the radio frequency system **12**, input structures **14**, memory **16**, one or more processor(s) **18**, one or more storage devices **20**, a power source **22**, input/output ports **24**, and an electronic display **26**. The various components described in FIG. 1 may include hardware elements (including circuitry), software elements (including instructions stored on a non-transitory computer-readable medium), or a combination of both hardware and software elements. It should be noted that FIG. 1 is merely one example of a particular implementation and is intended to illustrate the types of components that may be present in the electronic device **10**. Additionally, it should be noted that the various depicted components may be combined into fewer components or separated into additional components. For example, the memory **16** and a storage device **20** may be included in a single component.

As depicted, the processor **18** is operably coupled with memory **16** and the storage device **20**. More specifically, the processor **18** may execute instruction stored in memory **16** and/or the storage device **20** to perform operations in the electronic device **10**, such as instructing the radio frequency system **12** to communicate with another device. As such, the processor **18** may include one or more general purpose microprocessors, one or more application specific processors (ASICs), one or more field programmable logic arrays (FPGAs), or any combination thereof. Additionally, memory **16** and/or the storage device **20** may be a tangible, non-transitory, computer-readable medium that stores instructions executable by and data to be processed by the processor **18**. For example, the memory **16** may include random access memory (RAM) and the storage device **20** may include read only memory (ROM), rewritable flash memory, hard drives, optical discs, and the like.

Additionally, as depicted, the processor **18** is operably coupled to the power source **22**, which provides power to the various components in the electronic device **10**. As such, the power source **22** may include any suitable source of energy, such as a rechargeable lithium polymer (Li-poly) battery and/or an alternating current (AC) power converter. Furthermore, as depicted, the processor **18** is operably coupled with I/O ports **24**, which may enable the electronic device **10** to interface with various other electronic devices, and input structures **14**, which may enable a user to interact with the electronic device **10**. Accordingly, the inputs structures **14** may include buttons, keyboards, mice, trackpads, and the like. Additionally, in some embodiments, the electronic display **26** may include touch sensitive components.

In addition to enabling user inputs, the electronic display **26** may display image frames, such as a graphical user interface (GUI) for an operating system, an application interface, a still image, or video content. As depicted, the display is operably coupled to the processor **18**. Accordingly, the image frames displayed by the electronic display **26** may be based on display image data received from the processor **18**.

As depicted, the processor **18** is also operably coupled with the radio frequency system **12**, which may facilitate communicatively coupling the electronic device **10** to one or more other electronic devices and/or networks. For example, the radio frequency system **12** may enable the electronic device **10** to communicatively couple to a personal area network (PAN), such as a Bluetooth network, a local area network (LAN), such as an 802.11x Wi-Fi network, and/or a wide area network (WAN), such as a 4G or LTE cellular

network. As can be appreciated, the radio frequency system **12** may enable communication using various communication protocols.

Operational principles of the radio frequency system **12** may be similar for each of the communication protocols (e.g., Bluetooth, LTE, 802.11x Wi-Fi, etc). More specifically, as will be described in more detail below, the radio frequency system **12** may convert a digital electrical signal containing data desired to be transmitted into an analog electrical signal using a transceiver. The analog electrical signal may then be amplified using a power amplifier, filtered using a filter, and transmitted using an antenna. In other words, the techniques described herein may be applicable to any suitable radio frequency system **12** that operates in any suitable manner regardless of communication protocol used.

As described above, the electronic device **10** may be any suitable electronic device. To help illustrate, one example of a handheld device **10A** is described in FIG. **2**, which may be a portable phone, a media player, a personal data organizer, a handheld game platform, or any combination of such devices. For example, the handheld device **10A** may be a smart phone, such as any iPhone® model available from Apple Inc. As depicted, the handheld device **10A** includes an enclosure **28**, which may protect interior components from physical damage and to shield them from electromagnetic interference. The enclosure **28** may surround the electronic display **26**, which, in the depicted embodiment, displays a graphical user interface (GUI) **30** having an array of icons **32**. By way of example, when an icon **32** is selected either by an input structure **14** or a touch sensing component of the electronic display **26**, an application program may launch.

Additionally, as depicted, input structures **14** may open through the enclosure (e.g., housing) **28**. As described above, the input structures **14** may enable a user to interact with the handheld device **10A**. For example, the input structures **14** may activate or deactivate the handheld device **10A**, navigate a user interface to a home screen, navigate a user interface to a user-configurable application screen, activate a voice-recognition feature, provide volume control, and toggle between vibrate and ring modes. Furthermore, as depicted, the I/O ports **24** open through the enclosure **28**. In some embodiments, the I/O ports **24** may include, for example, an audio jack to connect to external devices. Additionally, the radio frequency system **12** may also be enclosed within the enclosure **28** and internal to the handheld device **10A**.

To further illustrate a suitable electronic device **10**, a tablet device **10B** is described in FIG. **3**, such as any iPad® model available from Apple Inc. Additionally, in other embodiments, the electronic device **10** may take the form of a computer **10C** as described in FIG. **4**, such as any Macbook® or iMac® model available from Apple Inc. As depicted, the tablet device **10B** and the computer **10C** also include an electronic display **26**, input structures **14**, I/O ports **24**, and an enclosure **28**. Similar to the handheld device **10A**, the radio frequency system **12** may also be enclosed within the enclosure **28** and internal to the tablet device **10B** and/or the computer **10C**.

As described above, the radio frequency system **12** may facilitate communication with other electronic devices and/or a network by wirelessly communicating data. To help illustrate, a portion **34** of radio frequency system **12** is described in FIG. **5**. As depicted, the portion **34** includes a digital signal generator **36**, a transceiver **38**, a power amplifier **40**, one or more filters **42**, a feedback coupler **39**, an antenna **44**, and a controller **41**. More specifically, the

controller **41** may include one or more processor **43** and memory **45** to facilitate controlling operation of the radio frequency system **12**. For example, the controller **41** may instruct the transceiver **38**, the power amplifier **40**, the one or more filters, the coupler **39**, or any combination thereof to adjust operational parameters. Accordingly, in some embodiments, the controller processor **43** may be included in the processor **18** and/or separate processing circuitry and the memory **45** may be included in memory **16** and/or a separate tangible non-transitory computer-readable medium.

Additionally, the digital signal generator **36** may generate a digital representation of data desired to be transmitted from the electronic device **10** by outputting a digital electrical signal. Accordingly, in some embodiments, the digital signal generator **36** may include the processor **18** and/or a separate processing circuitry, such as a baseband processor or a modem in the radio frequency system **12**.

The transceiver **38** may then receive the digital electrical signal and generate an analog representation of the data. In some embodiments, the transceiver **38** uses digital signal modulation to generate an analog representation as an analog electrical signal. For example, when the digital electrical signal is high (e.g., “1”), the transceiver **38** may output an analog electrical signal with a positive voltage and, when the digital electrical signal is low (e.g., “0”), the transceiver **38** may output an analog electrical signal at zero volts. However, digital signal modulation used in the transceiver **38** may generally introduce some noise into the analog electrical signal.

Since the output power of the analog electrical signal may be small, the power amplifier **40** may receive and amplify the analog electrical signal by outputting an amplified analog electrical signal. More specifically, the power amplifier **40** may vary amplitude of the amplified analog electrical signal to enable the output power of the radio frequency system **12** to be adjusted. In fact, in some embodiments, the power amplifier **40** may mix noise/distortions introduced by the transceiver **38**, thereby introducing intermodulation spurious emissions.

Additionally, in some embodiments, the power amplifier **40** may include one or more transistors as electrical switches to amplify the analog electrical signal. Ideally, the power amplifier **40** should linearly adjust amplitude (e.g., output power) of the amplified analog electrical signals and maintain a constant phase shift between the input analog electrical signals and the output amplified analog electrical signals. However, transistors are generally not ideal (e.g., parasitic capacitance, memory effects, and/or a non-linear input to output transfer function), which may affect linearity and/or phase shift of the power amplifier **40**. For example, if amplitude modulation (AM) peaks exceed the drive capability of the power amplifier **40**, the power amplifier compression may result, thereby causing AM-AM (amplitude modulation to amplitude modulation) and/or AM-PM (amplitude modulation to phase modulation) distortion. This distortion may result in impairments, such as error vector magnitude (EVM), on the in-band portion of the transmitted analog electrical signal (e.g., at the desired transmission frequency), thereby degrading signal integrity. In other words, the effects on linearity and/or phase shift in the power amplifier **40** may generally introduce noise or distortion into the amplified analog electrical signal.

To facilitate reducing noise introduced by the transceiver **38** and/or the power amplifier **40**, one or more filters **42** may receive the amplified analog electrical signal and output a filtered analog electrical signal. More specifically, the one or more filters **42** may be tuned to attenuate portions of the

amplified analog electrical signal at target frequencies, such as protected frequencies. However, since filters are generally not ideal, the one or more filters **42** may include a transition band that affects frequencies other than the target frequencies. In fact, when attenuating frequencies near the transmission frequency, the transition band may reduce the amplitude at the transmission frequency, thereby reducing output power of the radio frequency system **12**.

The filtered analog electrical signal may then be wirelessly transmitted to another electronic devices and/or a network via the antenna **44** at a transmission frequency as modulated radio waves. The transmitted analog electrical signal may also be fed back from the coupler **39** to a feedback receiver **47**, which may be used to facilitate controlling output power of the radio frequency system **12**. In some embodiments, the feedback receiver **47** may be tuned to the portion of the transmitted analog electrical signal at the transmission frequency and surrounding frequencies (e.g., frequencies in adjacent channels). Additionally or alternatively, the feedback receiver **47** may be tuned to portions of the transmitted analog electrical signal at particular target frequencies (e.g., protected frequencies). In this manner, as will be described in more detail below, the feedback of the transmitted analog electrical signal may also facilitate determining location (e.g., frequency) and/or magnitude of spurious emissions.

As described above, noise or distortion introduced by the radio frequency system **12** may result in spurious emissions at frequencies other than the desired transmission frequency. To help illustrate, examples of analog electrical signals **46** are described in FIGS. **6A** and **6B**. More specifically, FIG. **6A** describes a first analog electrical signal **46A** that is transmitted when the radio frequency system **12** is assigned fifty resource blocks (e.g., 10 MHz) and FIG. **6B** describes a second electrical signal **46B** that is transmitted when the radio frequency system **12** is assigned one resource block. In the depicted embodiments, the radio frequencies are divided into channels with a bandwidth of 10 MHz. As such, FIGS. **6A** and **6B** describe the magnitude of the analog electrical signals **46** in a first channel **48** between 675-685 MHz, a second channel **50** between 685-695 MHz, a third channel **52** between 695-705 MHz, a fourth channel **54** between 705-715 MHz, and a fifth channel **56** between 715-725 MHz. It should be noted that the analog electrical signals **46** are merely intended to be illustrative and not limiting.

With regard to FIG. **6A**, since the radio frequency system **12** is assigned fifty resource blocks, the first analog electrical signal **46A** has a desired transmission bandwidth of 10 MHz. Thus, as depicted, the analog electrical signal **46A** includes a data portion **58A** at the frequencies between 695-705 MHz. More specifically, the data portion **58A** includes the analog representation of data desired to be wirelessly transmitted to another electronic device and/or a network.

However, the data portion **58A** may also include noise or distortion introduced, for example, by the transceiver **38**. As such, when the introduced noise or distortion is mixed in the power amplifier **40**, intermodulation spurious emissions may result. Generally odd order intermodulation spurious emissions occur near the transmission frequency. More specifically, 3rd order intermodulation spurious emissions may occur in channels directly adjacent to the transmission channel, 5th order intermodulation spurious emissions may occur at channels two channels away from the transmission channel, 7th order intermodulation spurious emissions may occur at channels three channels away from the transmission channel, and so on. For example, in the depicted embodiment, 3rd order intermodulation spurious emissions **60A**

with a 10 MHz bandwidth occur in the second channel **50** and the fourth channel **54**. Additionally, 5th order intermodulation spurious emissions **62A** with a 10 MHz bandwidth occur in the first channel **48** and the fifth channel **56**.

With regard to FIG. **6B**, since the radio frequency system **12** is assigned one resource block, the second analog electrical signal **46B** has a desired transmission bandwidth of 0.2 MHz. In the depicted embodiment, the second analog electrical signal **46B** includes a data portion **58B** at frequencies around 695 MHz (e.g., edge of the third channel **52**). More specifically, the data portion **58B** includes the analog representation of data desired to be wirelessly transmitted to another electronic device and/or a network.

However, in addition to the data portion **58B**, the analog electrical signal **46B** also includes a local oscillator (LO) spurious emission **63** at frequencies around 700 MHz and an in-phase quadrature (IQ) spurious emission **64** at frequencies around 705 MHz. In some embodiments, the local oscillator spurious emission **63** may be introduced by the transceiver **38** at the central frequencies of the channel (e.g., 700 MHz) since the transceiver **38** is generally tuned to the central frequencies. Additionally, the in-phase quadrature spurious emission **64** may also be introduced by imperfections of the transceiver **38** and occur at frequencies such that the local oscillator spurious emission **63** is between and equidistant from the data portion **58B** and the in-phase quadrature spurious emission **64**.

Additionally, when the data portion **58B**, the local oscillator spurious emissions **63**, and the in-phase quadrature spurious emission **64** are mixed in the power amplifier **40**, intermodulation spurious emissions may result. For example, in the depicted embodiment, 3rd order intermodulation spurious emissions **60B** occur in the second channel **50** at frequencies around 690 MHz (e.g., as a result of intermodulation between the data portion **58B** and local oscillator spurious emission **63**) and at frequencies around 685 MHz (e.g., as a result of intermodulation between the data portion **58B** and the in-phase quadrature spurious emission **64**). Similarly, 3rd order intermodulation spurious emission **60B** occur in the fourth channel **54** at frequencies around 710 MHz and 715 MHz. Additionally, 5th order intermodulation spurious emissions **62A** occur in the first channel **48** at frequencies around 675 MHz and 680 MHz and in the fifth channel **56** at frequencies around 720 MHz and 725 MHz.

However, as described above, regulatory bodies may place acceptable limits on spurious emissions (e.g., intermodulation spurious emissions **60** and **62**), particularly at protected/restricted frequency ranges. For example, the FCC limits spurious emissions at frequencies between 608-614 MHz to 200 microvolts/meter. Thus, continuing with the above examples, it is possible that transmitting the analog electrical signals **46** may result in a higher order (e.g., 19th order) intermodulation spurious emission occurring in between 608-614 MHz. Moreover, if the analog electrical signals **46** use a lower transmission frequency (e.g., 615 MHz), it may be possible that lower order intermodulation spurious emissions (e.g., **60** or **62**) may occur between 608-614 MHz.

As such, the radio frequency system **12** may be operated such that spurious emissions meet set spurious emissions limits. To help illustrate, one embodiment of a process **66** for controlling operation of a radio frequency system **12** is described in FIG. **7**. Generally, the process **66** includes determining spurious emissions limits (process block **68**), determining transmitted spurious emissions (process block **70**), determining whether spurious emissions are greater

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than the spurious emissions limits (decision block 72), and transmitting analog electrical signals using nominal operational parameters when the spurious emissions are not greater than the limits (process block 74). Additionally, when the spurious emissions are greater than the limits, the process 66 includes adjusting the operational parameters of the radio frequency system (process block 76) and transmitting the analog electrical signals using adjusted operational parameters (process block 78). Furthermore, the process 66 optionally includes offsetting the spurious emissions (process block 71). In some embodiments, the process 66 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

Accordingly, the radio frequency system 12 may determine any set spurious emissions limits (process block 68). As described above, the spurious emissions limits regulating location (e.g., frequency) and/or magnitude of spurious emissions may be predetermined and set by regulatory bodies. Thus, in some embodiments, a manufacturer may store any such spurious emissions limits in memory (e.g., 16 or 45) upon manufacture. Thus, upon powering on, the radio frequency system 12 may poll the memory to determine spurious emissions limits. Additionally or alternatively, to facilitate operating under jurisdictions of various regulating bodies, the radio frequency system 12 may receive spurious emissions limits for a particular jurisdiction from a network upon powering up.

Additionally, the radio frequency system 12 may determine the location (e.g., frequency) and/or magnitude of spurious emissions transmitted (process block 70). As described above, the spurious emissions may vary based on operational parameters, such as ambient temperature, transmission frequency, output power, antenna load, and the like. Accordingly, in some embodiments, as will be described in more detail below, the radio frequency system 12 may determine the operational parameters and supply the operational parameters to a model, which relates the operational parameters to spurious emissions.

Additionally or alternatively, as described above, the radio frequency system 12 may determine the spurious emissions based at least in part on a feedback signal received from the coupler 39. To help illustrate, one embodiment of a process 80 for determining spurious emissions based on the feedback signal is described in FIG. 8. Generally, the process 80 includes determining a desired (e.g., ideal) signal (process block 82), determining a feedback signal (process block 84), and comparing the desired signal and the feedback signal (process block 86). In some embodiments, the process 80 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

Accordingly, the radio frequency system 12 may determine the desired signal (process block 82). More specifically, the desired signal represents the data to be transmitted without any noise or distortion. As such, the desired signal may be the digital electrical signal received from the digital signal generator 36 because the digital electrical signal does not include noise or distortion introduced by the transceiver 38 and/or the power amplifier 40.

Additionally, the radio frequency system 12, and more particularly the feedback receiver 47, may determine the feedback signal from the coupler 39 (process block 84). As described above, the feedback receiver 47 may determine

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portions of the transmitted analog electrical signal at frequencies surrounding the transmission frequency to facilitate controlling output power of the radio frequency system 12. Accordingly, in some embodiments, the feedback receiver 47 may be shared and tuned to the portion of the transmitted analog electrical signal at frequencies surrounding the transmissions frequency. Additionally or alternatively, the feedback receiver 47 may be dedicated and tuned to portions of the transmitted analog electrical signal at specific frequencies.

In either embodiment, the radio frequency system 12 may determine location (e.g., frequency) and/or magnitude by comparing the desired signal with the feedback signal (process block 88). More specifically, the radio frequency system 12 may determine location of spurious emissions based on frequencies at which the desired signal and the feedback signal differ. Additionally, the radio frequency system 12 may determine magnitude of the spurious emission based on difference between the desired signal and the feedback signal at those locations.

To help illustrate, one embodiment of a process 90 for determining spurious emissions using a dedicated feedback receiver 47 is described in FIG. 9. Generally, the process 90 includes determining a target frequency (process block 92), setting a feedback receiver to the target frequency (process block 94), determining feedback signal at the target frequency (process block 96), and determining spurious emissions at the target frequency (process block 98). In some embodiments, the process 90 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

Accordingly, the radio frequency system 12 may determine the target frequency (process block 92) and set the feedback receiver 47 accordingly (process block 94). In some embodiments, the target frequency may be set to protected/restricted frequencies that are likely to contain spurious emissions above a set limit. The feedback receiver 47 may then be tuned to determine portions of the analog electrical signal 46 at the target frequency and possibly surrounding frequencies.

In this manner, the radio frequency system 12 may determine any spurious emissions at the target frequency by comparing the desired signal at the target frequency and the feedback signal at the target frequency (process block 98). More specifically, the radio frequency system 12 may determine that spurious emissions occur at the target frequency when the desired signal and the feedback signal differ. Additionally, the radio frequency system 12 may determine magnitude of the spurious emissions at the target frequency based on amount of difference between the desired signal and the feedback signal at the target frequency.

In other words, the use of a dedicated feedback receiver 47 enables explicitly determining location and/or magnitude of spurious emissions at one or more target frequencies. However, to reduce components and/or cost of the radio frequency system 12, a shared feedback receiver 47 may still be used to determine location and/or magnitude by calculating spurious emissions based on feedback of the portion of the transmitted analog electrical signal at frequencies surrounding the transmission frequency (e.g., transmission channel and adjacent channels).

To help illustrate, one embodiment of a process 100 for determining spurious emissions using a shared feedback receiver 47 is described in FIG. 10. Generally, the process 100 includes determining feedback signal at a transmission

channel (process block 102), determining feedback signal at adjacent channels (process block 104), and determining spurious emissions at other frequencies (process block 106). Additionally, process 100 may optionally include adjusting a relationship between the intermodulation spurious emissions (process block 108). In some embodiments, the process 100 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

As described above, a shared feedback receiver 47 may be used to facilitate controlling output power by determining the portion of the transmitted analog electrical signal at the transmission frequency. Since the feedback receiver 47 may have a bandwidth of multiple channels, the feedback signal may include the portion of the transmitted analog electrical signal in the transmission channel, which includes the transmission frequency (process block 102), as well as the portion of the transmitted analog electrical signal in channels adjacent to the transmission channel (process block 104). As such, the radio frequency system 12 may explicitly determine location and/or magnitude of spurious emissions in the transmission channel and the adjacent channels by comparing the feedback signal with the desired signal.

More specifically, lower order intermodulation spurious emissions (e.g., 60 and/or 62) generally occur in frequencies surrounding the transmission frequency and, thus, may be explicitly determined. However, since higher order intermodulation spurious emissions may occur multiple channels away, they may be outside of the feedback receiver 47 bandwidth. Nevertheless, the radio frequency system 12 may still determine (e.g., infer) location and/or magnitude of such intermodulation spurious emissions based on the signal integrity of the in-band feedback signal.

As discussed above, an odd order intermodulation emission (e.g., 60 or 62) generally occurs at each channel on either side of the transmission channel. As such, the radio frequency system 12 may determine the location (e.g., channel) of the intermodulation spurious emissions based at least in part on this relationship. For example, as discussed in FIGS. 6A and 6B, since the transmission channel is the third channel 52, the 3rd order intermodulation spurious emissions 60 occur in the second channel 50 and the fourth channel 54 and the 5th order intermodulation spurious emissions 62 occur in the first channel 48 and the fifth channel 56.

Additionally, the magnitudes of the odd order intermodulation spurious emissions are generally related. For example, in some embodiments, magnitudes of the odd order intermodulation spurious emissions may be related such that magnitude of the 3rd order intermodulation spurious emission has a 3:1 ratio, magnitude of the 5th order intermodulation spurious emission has a 5:1 ratio, magnitude of the 7th order intermodulation spurious emission has a 7:1 ratio, and so on. Accordingly, since the 3rd intermodulation spurious emission 60 and/or the 5th intermodulation spurious emission 62 generally occurs in an adjacent channels and are fed back, the radio frequency system 12 may determine the magnitude of the higher order intermodulation spurious emissions based on the relationship between the magnitudes.

In some embodiments, the relationship between the magnitudes of the odd order intermodulation spurious emissions may be predetermined by a manufacturer and stored in memory (e.g., 16 or 45) as a look-up-table (LUT) or a

tudes of the odd order intermodulation spurious emissions may be updated over the course of operation of the radio frequency system 12 (process block 108). For example, if the feedback receiver 47 has bandwidth capable of measuring multiple odd order intermodulation spurious emissions, the radio frequency system 12 may determine whether the measured magnitudes are consistent with the determined relationship and adjust the relationship (e.g., model or LUT) accordingly.

Additionally, since the spurious emissions may vary based on operational parameters, a model describing relationship between spurious emissions and various operational parameters may be used to determine spurious emissions. To help illustrate, one embodiment of a process 110 for determining spurious emissions using a model is described in FIG. 11. Generally, the process 110 includes determining a model of spurious emissions (process block 112), determining operational parameters (process block 114), and determining spurious emissions (process block 116). Additionally, the process 110 optionally includes adjusting the model of spurious emissions (process block 118). In some embodiments, the process 110 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

Accordingly, the radio frequency system 12 may determine the model describing relationship between spurious emissions and operational parameters (process block 112). In some embodiments, the model may be determined by a manufacturer and stored in memory (e.g., 16 or 45). More specifically, the manufacturer may run a testing or training sequence to determine how sets of operational parameters affect spurious emissions. For example, the manufacturer may determine the location and magnitude of spurious emissions at varying ambient temperatures, transmission frequencies, output powers, and antenna loads.

The radio frequency system 12 may then determine the operational parameters that are inputs to the model (process block 114). In some embodiments, this may include polling various sensors (e.g., temperature sensors) and/or the memory to determine various operational parameters. For example, the radio frequency system 12 may poll a temperature sensor to determine ambient temperature. Additionally, the radio frequency system 12 may poll memory to determine a desired transmission frequency, a desired output power, current antenna load, or any combination thereof.

In this manner, the radio frequency system 12 may determine location and/or magnitude of spurious emissions by inputting the operational parameters into the model (process block 116). Moreover, since the radio frequency system 12 may still include a shared feedback receiver 47 to facilitate controlling output power, the radio frequency system 12 may determine portions of the transmitted analog electrical signal at the transmission channel and adjacent channels, thereby enabling the radio frequency system 12 to determine spurious emissions in the transmission channel and adjacent channels. As such, the radio frequency system 12 may determine whether the measured magnitudes are consistent with the model and adjust the model accordingly.

Returning to FIG. 7, once the spurious emissions are determined, the radio frequency system 12 may optionally offset the spurious emissions (process block 71). As described above, the spurious emissions may be a result of noise introduced by the transceiver 38 and/or the power amplifier 40. Accordingly, to offset the spurious emissions, the transceiver 38 may generate the analog electrical signal

such that it includes an inverse of the noise introduced by the transceiver **38** and/or the power amplifier **40**. In this manner, the noise introduced by the transceiver **38** and/or the power amplifier **40** may be canceled out, thereby reducing spurious emissions.

Additionally, the radio frequency system **12** may determine whether the spurious emissions are greater than set limits (decision block **72**). When not greater than the limits, the radio frequency system may transmit the analog electrical signals using nominal operational parameters (process block **74**). More specifically, the nominal operational parameters may be a set of operational parameters that balance ability of the radio frequency system **12** to meet spurious emissions limits, efficiency (e.g., output power/DC power consumption), and reliability of transmission.

On the other hand, when greater than the limits, the radio frequency may adjust the operational parameters away from the nominal operational parameters to reduce spurious emissions below the limits (process block **76**). For example, adjusting the operational parameters may include adjusting filter rejection (process block **120**), decreasing amplification by the power amplifier (process block **122**), increasing power amplifier linearity (process block **124**), adjusting skew of power amplifier (process block **126**), or any combination thereof.

In some embodiments, the radio frequency system **12** may adjust the one or more filters **42** to control frequencies targeted by the filters **42** and/or aggressiveness of the filtering (process block **120**). More specifically, the radio frequency system **12** may tune the filters **42** to target particular frequencies at which to reduce spurious emissions. As such, the filters **42** may be tuned to particular frequencies where spurious emissions are exceeding limits. Additionally, the aggressiveness the filters **42** may be adjusted to control amount the spurious emissions are attenuated (e.g., reduced) at the target frequencies.

However, as described above, the filters **42** generally include a transition band and, thus, may affect frequencies other than the target frequencies. For example, when the filters **42** are tuned to a frequency near the transmission frequency, the transition band of the filters **42** may also attenuate the transmitted analog electrical signal at the transmissions frequency. Moreover, as the aggressiveness increases, the frequencies affected by the transition band may increase as well as the magnitude of the attenuation at the affected frequencies.

In other words, the tuning and/or aggressiveness of the filters **42** may affect the output power of the transmitted analog electrical signals. To compensate, the radio frequency system **12** may increase the amplification by the power amplifier **40**. However, increasing amplification may consume a greater amount of electrical power to achieve the same output power, thereby decreasing efficiency (e.g., output power/DC power consumption) of the radio frequency system **12**. In fact, to improve efficiency, under nominal operational parameters, the radio frequency system **12** may utilize less aggressive filtering or even bypass the filters **42** entirely. As such, adjusting the filter rejection away from the nominal operational parameters may affect performance of the radio frequency system **12**, for example, by decreasing output power and/or decreasing efficiency.

Additionally, in some embodiments, the radio frequency system **12** may decrease amplification by the power amplifier **40** to reduce magnitude of spurious emissions over the spectrum of the transmitted analog electrical signals (process block **122**). More specifically, the magnitude of intermodulation spurious emissions (e.g., **60** or **62**) may be

directly related to the output power of the transmitted analog electrical signal. In other words, by decreasing output power of the transmitted analog electrical signal as a whole via reduction in amplification by the power amplifier **40**, the magnitude of the spurious emissions may also be decreased.

However, reducing output power of the radio frequency system **12** may affect reliability of communication with the other electronic device and/or the network. For example, a lower output power may increase the risk of data packets being dropped. In some embodiments, this may cause the radio frequency system **12** to resend the dropped data packets, which consumes additional electrical power, or simply proceed without the dropped packets, which may affect communication (e.g., call) quality. In fact, under nominal operational parameters, the radio frequency system **12** may utilize amplification in the power amplifier **40** that balances efficiency and communication reliability. As such, adjusting amplification away from the nominal operational parameters may affect performance of the radio frequency system **12**, for example, by decreasing efficiency and/or decreasing communication reliability.

Furthermore, in some embodiments, the radio frequency system **12** may increase linearity of the power amplifier **40** to reduce noise introduced by the power amplifier **40** (process block **124**). As described above, the power amplifier **40** may introduce noise due to a non-linear relationship between amplitude of the input and output analog electrical signals and/or an inconsistent phase shift between the input and output analog electrical signals, which vary based on output power. Thus, improving linearity of the power amplifier **40** may decrease amount of noise introduced, thereby reducing spurious emissions.

Generally, linearity may be improved by increasing electrical power supplied to the power amplifier **40**. As such, increasing linearity to achieve the same output power may decrease efficiency (e.g., output power/DC power consumption) of the radio frequency system **12**. In fact, under nominal operational parameters, the radio frequency system **12** may utilize a linearity of the power amplifier **40** that balances efficiency and introduced noise. As such, adjusting amplification away from the nominal operational parameters may affect performance of the radio frequency system **12**, for example, by decreasing efficiency.

Moreover, in some embodiments, the radio frequency system **12** may adjust the skew of the power amplifier **40** to adjust location (e.g., frequency) of the spurious emissions (process block **126**). For example, when the power amplifier **40** utilizes envelope tracking, the skew of the power amplifier **40** may be adjusted to shift spurious emissions from one side of the transmission frequency to the other. In other words, spurious emissions at some frequencies may be improved at the expense of others. This may be particularly useful when protected/restricted frequencies occur closer on one side of the transmission frequency.

However, since the location of protected/restricted frequencies may vary based on jurisdiction, under nominal operational parameters, the radio frequency system **12** may utilize a skew that evenly spreads the spurious emissions on either side of the transmission frequency. As such, adjusting skew of the power amplifier **40** away from the nominal operational parameters may affect performance of the radio frequency system **12**, for example, by introducing spurious emissions at other frequencies.

Once the operational parameters of the radio frequency system **12** are adjusted using any combination of the techniques described above, the radio frequency system **12** may transmit subsequent analog electrical signals using the

adjusted operational parameters while meeting any spurious emissions limits (process block 78). As described above, each of the techniques that may be employed to adjust the operational parameters introduce different tradeoffs. Accordingly, it may be desirable to employ techniques based at least in part on type, location, magnitude, and/or number of the spurious emissions.

To help illustrate, one embodiment of a process 128 for determining the adjustments to the operational parameters is described in FIG. 12. Generally, the process 128 includes determining magnitude, location, number, and type of spurious emissions that exceed limits (process block 130) and determining adjustments on operational parameters (process block 132). In some embodiments, the process 128 may be implemented using instructions stored in the memory 16, 45 and/or another suitable tangible non-transitory computer-readable medium and executable by the processor 18, 43, and/or another suitable processing circuitry.

Accordingly, as described above, the radio frequency system 12 may determine magnitude and location of spurious emissions, for example, using a feedback signal and/or a model of spurious emissions. Additionally, the radio frequency system 12 may determine number of spurious emissions based at least in part on number of instances the feedback signal differs from a desired signal. Furthermore, the radio frequency system 12 may determine the type of each spurious emission based on location of the spurious emission. For example, when the spurious emissions are in set intervals from the transmission channel, the radio frequency system 12 may determine that the spurious emissions are intermodulation spurious emissions (e.g., 60 or 62). Spurious emissions at integer multiples of the desired transmission frequency may be identified as harmonics. Emissions type and location may also be known to the controller 41 in advance based on the type of signal being transmitted.

Based at least in part on the magnitude, location, type, and number of the spurious emissions, the radio frequency system 12 may then determine what techniques to employ when adjusting the operational parameters (process block 132). For example, when spurious emissions exceed limits at a large number of frequencies, the radio frequency system 12 may determine that reducing amplification by the power amplifier 40 should be used to enable decreasing spurious emissions across the spectrum of the transmitted analog electrical signal. Additionally, when power consumption is not a concern (e.g., when electronic device 10 connected to a wall outlet), the radio frequency system 12 utilize adjusting filter rejection and/or increasing power amplifier 40 linearity. Furthermore, when intermodulation spurious emissions exceed limits, the radio frequency system 12 may determine to increase power amplifier 40 linearity to reduce noise introduced by the power amplifier 40 that cause the intermodulation spurious emissions (e.g., 60 or 62). Moreover, when spurious emission (e.g., 60 or 62) exceed limits on one side of the transmission frequency but not the other, the radio frequency system 12 may determine to adjust skew of the power amplifier 40 to shift location of leakage spurious emissions.

Accordingly, the technical effects of the present disclosure include improving performance of a radio frequency system by adjusting operation based at least in part on spurious emissions. More specifically, the radio frequency system may predominantly operate using nominal operational parameters, which may strike a balance between efficiency (e.g., output power/DC power consumption) and reliability. However, since occurrence of spurious emissions

may vary over operation, the radio frequency system may adjust the operational parameters away from the nominal operational parameters so that spurious emissions limits are not exceeded. In this manner, the nominal operational parameters may be set more aggressively, thereby improving efficiency and/or reliability, since the operational parameters may be dynamically adjusted when spurious emissions exceed set limits.

The specific embodiments described above have been shown by way of example, and it should be understood that these embodiments may be susceptible to various modifications and alternative forms. It should be further understood that the claims are not intended to be limited to the particular forms disclosed, but rather to cover all modifications, equivalents, and alternatives falling within the spirit and scope of this disclosure.

What is claimed is:

1. A radio frequency system configured to wirelessly transmit data, comprising:

a power amplifier configured to operate using a first operational parameter to generate a first amplified analog electrical signal based at least in part on a first digital electrical signal, wherein the first digital electrical signal comprises a first digital representation of first data and the first operational parameter comprises amplification applied by the power amplifier, a linearity of the power amplifier, a skew of the power amplifier, or any combination thereof;

a filter configured to operate using a second operational parameter to generate a first filtered analog electrical signal based at least in part on the first amplified analog electrical signal, wherein the second operational parameter comprises a target filtering frequency of the filter, a filtering aggressiveness applied by the filter, or both;

an antenna configured to wirelessly transmit a first output analog electrical signal based at least in part on the first filtered analog electrical signal, wherein the first output analog electrical signal comprises a first analog representation of the first data at a target transmission frequency and a first spurious emission at a frequency other than the target transmission frequency; and

a controller configured to:

determine a first location and a first magnitude of the first spurious emission by comparing at least a portion of the first output analog electrical signal with the first digital electrical signal; and

instruct the radio frequency system to adjust the first operational parameter, the second operational parameter, or both when the first magnitude is greater than a spurious emission limit at the first location.

2. The radio frequency system of claim 1, wherein, after the radio frequency system adjusts the first operational parameter, the second operational parameter, or both:

the power amplifier is configured to operate using the first operational parameter to generate a second amplified analog electrical signal based at least in part on a second digital electrical signal, wherein the second digital electrical signal comprises a second digital representation of second data;

the filter is configured to operate using the second operational parameter to generate a second filtered analog electrical signal based at least in part on the second amplified analog electrical signal; and

the antenna is configured to wirelessly transmit a second output analog electrical signal after the first output analog electrical signal based at least in part on the

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second filtered analog electrical signal, wherein the second output analog electrical signal comprises a second analog representation of the second data at the target transmission frequency and a second spurious emission with a second magnitude not greater than the spurious emission limit at the first location.

3. The radio frequency system of claim 1, comprising a feedback receiver configured to determine a first feedback signal comprising a first portion of the first output analog electrical signal, wherein:

the first portion comprises a second spurious emission and not the first spurious emission; and

the controller is configured to:

determine a second location and a second magnitude of the second spurious emission by comparing the first feedback signal with the first digital electrical signal; determine the first location of the first spurious emission based at least in part on the second location of the second spurious emission and a first model configured to describe a first relationship between locations of spurious emissions; and

determine the first magnitude of the first spurious emission based at least in part on the second magnitude of the second spurious emission and a second model configured to describe a second relationship between magnitudes of spurious emissions.

4. The radio frequency system of claim 3, wherein:

the feedback receiver is configured to determine a second feedback signal comprising a second portion of the first output analog electrical signal, wherein the second portion comprises the first spurious emission; and

the controller is configured to:

determine an actual location of the first spurious emission by comparing the second feedback signal with the first digital electrical signal;

adjust the first model when the first location and the actual location of the first spurious emission are different;

determine an actual magnitude of the first spurious emission by comparing the second feedback signal with the first digital electrical signal; and

adjust the second model when the first magnitude and the actual magnitude of the first spurious emission are different.

5. The radio frequency system of claim 1, comprising a transceiver configured to:

receive the first digital electrical signal from a digital signal generator; and

convert the first digital electrical signal into an analog electrical signal using digital signal modulation, wherein:

the power amplifier is configured generate the first amplified analog electrical signal by amplifying a magnitude of the analog electrical signal; and

the transceiver, the power amplifier, or both are configured to introduce noise that causes the first spurious emission.

6. The radio frequency system of claim 1, wherein, when the first magnitude is greater than the spurious emission limit at the first location, the controller is configured to:

instruct the power amplifier to reduce amplification applied to generate the first amplified analog electrical signal;

instruct the filter to increase filtering aggressiveness and instruct the power amplifier to increase the amplification;

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instruct the power amplifier to adjust skew to move the first spurious emission from the first location to a second location;

instruct a power supply to increase electrical power supplied to the power amplifier to increase linearity of the power amplifier; or

instruct the filter to adjust a target filtering frequency based at least in part on the first location.

7. A method for operating a radio frequency system, comprising:

determining, using a controller in the radio frequency system, a digital electrical signal comprising a digital representation of data to be wirelessly transmitted from the radio frequency system;

determining, using the controller, a first location and a first magnitude of a first spurious emission expected to be wirelessly transmitted in a first output analog electrical signal, wherein the first output analog electrical signal comprises the first spurious emission and an analog representation of the data;

determining, using the controller, a magnitude limit on spurious emissions at the first location of the first spurious emission;

instructing, using the controller, the radio frequency system to wirelessly transmit the data using a first operational parameter set when the first magnitude of the first spurious emission is not greater than the magnitude limit, wherein instructing the radio frequency system to wirelessly transmit the data using the first operational parameter set comprises instructing a power amplifier to implement a first power amplifier operational parameter, a filter to implement a first filter operational parameter, or both, wherein:

instructing the power amplifier to implement the first power amplifier operational parameter comprises instructing the power amplifier to apply a first amplification, apply a first skew, implement a first linearity, or any combination thereof when generating an amplified analog electrical signal based at least in part on the digital electrical signal; and

instructing the filter to implement the first filter operational parameter comprises instructing the filter to apply a first filtering aggressiveness, target a first frequency, or both when generating the first output analog electrical signal based at least in part on the amplified analog electrical signal; and

instructing, using the controller, the radio frequency system to wirelessly transmit the data using a second operational parameter set when the first magnitude of the first spurious emission is greater than the magnitude limit, wherein instructing the radio frequency system to wirelessly transmit the data using the second operational parameter set comprises instructing the power amplifier to implement a second power amplifier operational parameter, the filter to implement a second filter operational parameter, or both, wherein:

instructing the power amplifier to implement the second power amplifier operational parameter comprises instructing the power amplifier to apply a second amplification value, apply a second skew, implement a second linearity, or any combination thereof when generating the amplified analog electrical signal; and

instructing the filter to implement the second filter operational parameter comprises instructing the filter to apply a second filtering aggressiveness, target a second frequency, or both when generating the first

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output analog electrical signal based at least in part on the amplified analog electrical signal.

8. The method of claim 7, wherein determining the first location and the first magnitude of the first spurious emission comprises:

instructing, using the controller, the radio frequency system to wirelessly transmit a second output analog electrical signal before the first output analog electrical signal;

determining, using the controller, a feedback signal comprising at least a portion of the second output analog electrical signal via a coupler;

determining, using the controller, a second location and a second magnitude of a second spurious emission in the second output analog electrical signal; and

determining, using the controller, the first location and the first magnitude of the first spurious emission based at least in part on the second location and the second magnitude of the second spurious emission.

9. The method of claim 7, wherein determining the first location and the first magnitude of the first spurious emission comprises:

determining, using the controller, a current value of radio frequency system operational parameters expected to affect location, magnitude, or both on output spurious emissions, wherein the radio frequency system operational parameters comprise a temperature of the radio frequency system, a target transmission frequency of the first output analog electrical signal, an output power of the first output analog electrical signal, a load on an antenna of the radio frequency system, or any combination thereof;

determining, using the controller, a spurious emissions model that describes a relationship between the radio frequency operational parameters, the location of spurious emissions, and the magnitude of spurious emissions; and

determining, using the controller, the first location and the first magnitude based at least in part on the current value of the radio frequency system operational parameters and the spurious emissions model.

10. The method of claim 9, comprising:

determining, using the controller, a feedback signal comprising at least a portion of the first output analog electrical signal via a coupler;

determining, using the controller, an actual location and an actual magnitude of the first spurious emission based at least in part on the feedback signal; and

adjusting, using the controller, the spurious emissions model when the first location and the actual location of the first spurious emission vary, the first magnitude and the actual magnitude of the first spurious emission vary, or both.

11. The method of claim 7, wherein determining the first location and the first magnitude of the first spurious emission comprises:

determining, using the controller, a second location and a second magnitude of a second spurious emission transmitted in the first output analog electrical signal;

determining, using the controller, a spurious emissions model that describes a first relationship between magnitude of spurious emissions and a second relationship between location of spurious emissions;

determining, using the controller, the first location of the first spurious emission based at least in part on the spurious emissions model and the second location of the second spurious emission; and

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determining, using the controller, the first magnitude of the first spurious emission based at least in part on the spurious emissions model and the second magnitude of the second spurious emission.

12. The method of claim 11, comprising:

determining, using the controller, a feedback signal comprising at least a portion of the first output analog electrical signal including the first spurious emission via a coupler;

determining, using the controller, an actual location and an actual magnitude of the first spurious emission based at least in part on the feedback signal; and

adjusting, using the controller, the spurious emissions model when the first location and the actual location of the first spurious emission vary, the first magnitude and the actual magnitude of the first spurious emission vary, or both.

13. The method of claim 7, wherein determining the magnitude limit comprises:

instructing, using the controller, the radio frequency system to communicatively couple to a network; and determining, using the controller, the magnitude limit based at least in part on received data from the network.

14. The method of claim 7, wherein determining the magnitude limit comprises:

determining, using the controller, a first value of the magnitude limit when the radio frequency system operates in a first geographic location; and

determining, using the controller, a second value of the magnitude limit when the radio frequency system operates in a second geographic location.

15. A tangible, non-transitory, computer-readable medium configured to store instructions executable by one or more processors of an electronic device configured to wirelessly transmit data, wherein the instructions comprise instructions to:

instruct, using the one or more processors, a radio frequency system in the electronic device to wirelessly transmit a first analog electrical signal by operating a power amplifier using a first power amplifier operational parameter, operating a filter using a first filter operational parameter, or both;

determine, using the one or more processors, first location and first magnitude of first spurious emissions wirelessly transmitted in the first analog electrical signal;

determine, using the one or more processors, a first set of radio frequency system operational parameters of the radio frequency system when wirelessly transmitting the first analog electrical signal; and

instruct, using the one or more processors, the radio frequency system to wirelessly transmit a second analog electrical signal after the first analog electrical signal based at least in part on transmission of the first analog electrical signal, wherein the instructions to instruct the radio frequency system to wirelessly transmit the second analog electrical signal comprise instructions to:

instruct the radio frequency system to wirelessly transmit the second analog electrical signal by operating the power amplifier using the first power amplifier operational parameter, the filter using the first filter operational parameter, or both when the first magnitude of each of the first spurious emissions is less than a corresponding spurious emissions limit; and instruct the radio frequency system to wirelessly transmit the second analog electrical signal by operating the power amplifier using a second power amplifier

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operational parameter different from the first power amplifier operational parameter, the filter using a second filter operational parameter different from the first filter operational parameter, or both, when the first magnitude of each of the first spurious emissions is not less than the corresponding spurious emissions limit.

16. The tangible, non-transitory, computer-readable medium of claim 15, wherein:

the first power amplifier operational parameter comprises a first amplification applied by the power amplifier, a first skew applied by the power amplifier, a first linearity implemented by the power amplifier, or any combination thereof;

the first filter operational parameter comprises a first frequency targeted by the filter, a first filtering aggressiveness applied by the filter, or both;

the second power amplifier operational parameter comprises a second amplification applied by the power amplifier, a second skew applied by the power amplifier, a second linearity implemented by the power amplifier, or any combination thereof;

the second filter operational parameter comprises a second frequency targeted by the filter, a second filtering aggressiveness applied by the filter, or both; and

the first set of radio frequency system operational parameters comprise a temperature of the radio frequency system, a target transmission frequency of the first

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analog electrical signal, an output power of the first analog electrical signal, a load on an antenna of the radio frequency system, or any combination thereof.

17. The tangible, non-transitory, computer-readable medium of claim 15, comprising instructions to:

determine, using the one or more processors, a spurious emissions model that describes a relationship between spurious emission in transmitted analog electrical signals and sets of radio frequency system operational parameters when transmitted analog electrical signals are transmitted;

determine, using the one or more processors, a second set of radio frequency system operational parameters expected to occur when the radio frequency system wirelessly transmits the second analog electrical signal;

determine, using the one or more processors, second location and second magnitude of second spurious emissions expected to be transmitted in the second analog electrical signal based at least in part on the spurious emissions model and the second set of radio frequency system operational parameters; and

instruct, using the one or more processors, the radio frequency system to wirelessly transmit the second analog electrical signal based at least in part on the second location and the second magnitude of the second spurious emissions.

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